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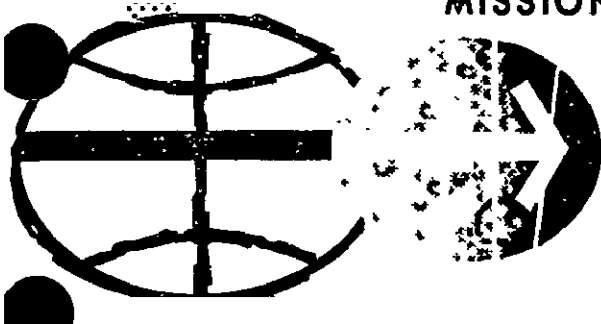
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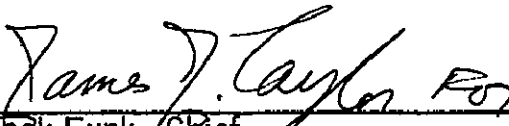
By Advanced Mission Design Branch

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April 9, 1970

MISSION PLANNING AND ANALYSIS DIVISION  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
MANNED SPACECRAFT CENTER  
HOUSTON, TEXAS

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REFERENCE MISSION: 1981 MARS LANDING WITH  
INBOUND VENUS SWINGBY

By Advanced Mission Design Branch

1.0 SUMMARY

A detailed description of a Mars landing mission is presented. The Earth departure sequence begins on November 7, 1981, with final injection occurring 67.51 hours later. The trip time to Mars orbit insertion is 266.55 days, and the spacecraft is inserted into an orbit with a 200-n. mi. altitude periapsis and a 6322.2-n. mi. altitude apoapsis. The orbit is inclined  $75^\circ$  to the Martian equator. A velocity maneuver of 6221 fps is required for orbit insertion. The landing operations begin 20 days after orbit insertion which results in a landing at  $69^\circ\text{N}$  latitude and  $130^\circ\text{E}$  longitude. The nominal surface staytime is 30 days, and the total orbit stay time is 80 days. The Mars parking orbit is designed to provide proper alinement for Mars departure which requires 12 929 fps. The trip time to Venus is 127 days, and the spacecraft closest approach to Venus is 2551 n. mi. The trip time from Venus to Earth is 169 days and the Earth entry velocity at a 400 000-foot altitude is 39 530 fps. The total mission trip time is 642 days.

## 2.0 INTRODUCTION

Preliminary spacecraft designs for planetary missions require the input of trajectory and mission planning data to be in the form of general parameteric studies. However, as the spacecraft design becomes better defined, a reference mission is needed to assess the spacecraft's capability to accomplish a particular mission. This document describes one such reference mission which departs Earth in 1981, stays for 80 days in an elliptical Mars orbit, deploys a manned lander which lands near the North polar cap (with a nominal surface staytime of 30 days) and returns to an aerodynamic entry at Earth by a close encounter (2500 n. mi.) with Venus.

The dynamic trajectory model used for this reference mission is the classic matched conic model in which the trajectory is divided into phases of (two-body) central force field motion defined by planetary spheres of influence. The exceptions to the unperturbed (two-body) motion occur during the Earth and Mars orbital phases when the apsidal and nodal regression rates are simulated. The Mars landing and launch trajectories are based on a central force field with aerodynamic and finite-thrust forces included. Thus, the landing and launch require numerical integration. All propulsive maneuvers are considered impulsive except for the final retrograde burn for landing and the launch from the Martian surface.

Although the Mars mission spacecraft is not discussed in this document, some concept of spacecraft and propulsion characteristics had to be assumed to derive the basic trajectory requirements. For example, the Earth departure sequence was developed based on the assumption of nuclear propulsion stages with 75 000-pound thrust and a postburn cooldown requirement. It is also apparent that the Mars lander descent/ascent profile could not be determined without certain assumptions of aerodynamic and propulsion characteristics. New or different spacecraft concepts will require new reference trajectory information; and, until the concepts become more firmly established, there is no requirement for precision integrated reference trajectories. The conic model provides the necessary accuracy for the spacecraft concept/trajectory design iteration and can (at least presently) be accomplished more rapidly.

This document is organized into a general discussion of the trajectory (mission profile and sequence of major events) followed by a detailed description of each mission phase. Suggestions for improving the organization and/or content of this document will be incorporated (where practical) in future planetary reference mission documents.

Extensive analysis was required both prior to and during the production of this trajectory as indicated by the list of references. Some of the references should probably be considered to be additional volumes of this



document but were published separately to obtain earlier release of data. However, this document represents the combined efforts of all personnel of the Advanced Mission Design Branch whether or not an individual's name is found in the list of references.

## 3.0 SYMBOLS.

|             |                                               |
|-------------|-----------------------------------------------|
| AOS         | acquisition of signal                         |
| ESOI        | Earth sphere of influence                     |
| $h_a$       | apoapsis altitude                             |
| $i$         | inclination                                   |
| LOS         | loss of signal                                |
| MEM         | Mars excursion module                         |
| MOI         | Mars orbit insertion                          |
| MSOI        | Mars sphere of influence                      |
| NERVA       | nuclear engine for rocket vehicle application |
| OLV         | orbital launch vehicle                        |
| SOI         | sphere of influence                           |
| TEI         | transearth injection                          |
| TMI         | trans-Mars injection                          |
| $t$         | time                                          |
| VSOI        | Venus sphere of influence                     |
| $W_0/C_D A$ | ballistic parameter                           |
| $\Omega$    | right ascension of the ascending node         |
| $\omega$    | argument of periapsis                         |

#### 4.0 MISSION PROFILE

The 1981 80-day Mars stopover/Venus swingby mission as discussed in this report is schematically illustrated in figure 1. The dashed line represents the flight path of the spacecraft which varies in distance from the sun from 0.538 A.U. to 1.495 A.U. The spacecraft passes within 0.2 A.U. of the planet Mercury. The mission incorporates a low-energy near  $180^\circ$  transfer for the Earth-to-Mars trajectory and a gravity turn by Venus to reduce the velocity requirements of the Mars-to-Earth trajectory. A matched conic trajectory program (ref. 1) was used to simulate Earth-to-Mars and the Mars-to-Earth portions of the mission.

The first maneuver of the trans-Mars injection sequence occurs on November 7, 1981. The above date is near the beginning of the Earth launch window for this mission as discussed in reference 2. The multiple orbit injection technique in which a low thrust-to-weight ratio of 0.05g is assumed is used for Earth orbit departure. The departure sequence consists of eight thrusting maneuvers with six intermediate elliptical orbits. The first six maneuvers occur at periapsis and increase the apoapsis altitude of the orbit. The seventh maneuver occurs near apoapsis of the final orbit and rotates the orbital plane such that it contains the departure asymptote. The eighth maneuver occurs at periapsis and gives the vehicle the necessary energy to attain the proper  $V_\infty$  vector. The entire departure sequence takes 67.51 hours to complete and involves a plane change of  $5.8^\circ$ . The departure sequence requires 13 253 fps including propulsive and nuclear engine cooldown propellant losses. The impulsive  $\Delta V$  requirement is 12 379 fps.

The Earth-to-Mars trip time for this reference mission is 266.55 days, and Mars orbit insertion consists of a single maneuver at periapsis of the approach hyperbola. The spacecraft's orbit at Mars is 200 by 6322.2 n. mi. The orbit was designed so that the perturbations of the Mars oblate gravitational field assist in reducing the velocity required for Mars orbit insertion and transearth injection.

The orbital staytime at Mars is 80 days, 30 days of which are spent on the Martian surface. The Mars excursion module (MEM) separates from the main spacecraft 20 days after orbit insertion and performs a retrograde maneuver to lower periapsis into the Martian atmosphere. This first aerodynamic phase is guided for a skip maneuver followed by a posigrade burn to circularize the orbit at a 180-n. mi. altitude. The MEM remains in this orbit until proper phasing is obtained with the landing site located at  $69^\circ\text{N}$  latitude and  $130^\circ\text{E}$  longitude. The MEM then performs a retrograde burn for the second aerodynamic phase which terminates at a 36 217-foot altitude with a velocity of 3451 fps. The main descent engines are started at this

altitude and provide a constant-flight-path angle descent to a 500-foot altitude and zero velocity. The descent from 500 feet was not simulated. No parachutes or ballutes were included in the simulation.

Ascent from the Martian surface occurs approximately 30 days after landing. The MEM ascent stage is inserted into an intermediate orbit with apoapsis altitude at 100 n. mi. and periapsis altitude at 300 000 feet. Orbit insertion occurs at  $5^\circ$  true anomaly. The first maneuver of the rendezvous sequence is initiated approximately six revolutions later and requires three burns. There are no significant aerodynamic perturbations to the intermediate phasing orbit (300 000 ft by 100 n. mi.) for coast times of up to several days. The actual coast time is 10.88 hours. The total time from lift-off to completion of rendezvous is 18.5 hours. The terminal phase of the rendezvous (i.e., stationkeeping and docking) is not simulated.

An impulsive maneuver of 12 929 fps places the spacecraft on a 127-day transfer to Venus. The Venus flyby altitude is 2551 n. mi. The spacecraft altitude is within 25 000 n. mi. of Venus for 2.5 hours. No propulsive maneuvers are required within the Venus sphere of influence (SOI).

The trip time from Venus flyby to Earth entry is 169 days. During this time, the spacecraft passes within 0.538 A.U. of the Sun. The Earth entry velocity is 39 531 fps measured at an altitude of 400 000 feet and occurs at  $14.2^\circ$ S latitude and  $165.7^\circ$ W longitude. The approach hyperbola is inclined  $28.2^\circ$  to the Earth's equator. The total trip time from Earth departure to Earth return is 642 days.

The sequence of major events are listed in table I; ground elapsed time and calendar date are given along with pertinent trajectory data. The assumed four-launch schedule is arbitrary and depends entirely on the booster systems available and the Mars spacecraft design. All refueling flights (if any) are assumed to occur between these launches.

TABLE I.- SEQUENCE OF MAJOR EVENTS

| Event                                    | Time, days<br>g.e.t. | Time           |                       | Data summary <sup>a</sup>                                                                                                                                                                |                                                     |
|------------------------------------------|----------------------|----------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|
|                                          |                      | Month/day/year | G.m.t.,<br>hr:min:sec |                                                                                                                                                                                          |                                                     |
| Launch 1                                 | -300.307             | 01/14/81       | 04:29:17              | Inclination of parking orbit, deg<br>Right ascension of ascending node, deg<br>Altitude of circular parking orbit, n. mi.                                                                | 29.16<br>42<br>260.33                               |
| Launch 2                                 | -210.246             | 04/14/81       | 05:57:07              | Right ascension of ascending node, deg                                                                                                                                                   | 153                                                 |
| Launch 3                                 | -120.184             | 07/13/81       | 07:26:24              | Right ascension of ascending node, deg                                                                                                                                                   | 263                                                 |
| Launch 4                                 | -30.124              | 10/11/81       | 08:52:48              | Right ascension of ascending node, deg                                                                                                                                                   | 14                                                  |
| Trans-Mars injection<br>(first maneuver) | -2.813               | 11/07/81       | 16:20:28              | Geographic latitude, deg<br>Geographic longitude, deg                                                                                                                                    | -23.3<br>109.6                                      |
| Trans-Mars injection<br>(last maneuver)  | 0.000                | 11/10/81       | 11:51:10              | Geographic latitude, deg<br>Geographic longitude, deg<br>Inclination, deg<br>Right ascension of ascending node, deg<br>Argument of periapsis, deg<br>Total accumulative $\Delta V$ , fps | -24.8<br>174.8<br>27.13<br>158.1<br>246.7<br>13 253 |
| Earth sphere of<br>influence (exit)      | 2.751                | 11/13/81       | 05:51:56              | Velocity, fps<br>Right ascension of velocity vector, deg<br>Declination of velocity vector, deg                                                                                          | 11 855<br>187.5<br>14.1                             |
| Mars sphere of<br>influence (entry)      | 264.871              | 08/02/82       | 08:46:11              | Velocity, fps<br>Right ascension of velocity vector, deg<br>Declination of velocity vector, deg                                                                                          | 12 859<br>118.3<br>-20.7                            |
| Mars orbit insertion                     | 266.551              | 08/04/82       | 01:04:05              | Right ascension, deg<br>Declination, deg<br>Geographic latitude, deg<br>Geographic longitude, deg<br>Impulsive velocity change, fps                                                      | 98.8<br>41.4<br>-12.3<br>239.6<br>6 221             |
| Mars parking orbit                       | 266.551              | 08/04/82       | 01:04:05              | Inclination, deg<br>Right ascension of ascending node, deg<br>Argument of periapsis, deg<br>Periapsis altitude, n. mi.<br>Apoapsis altitude, n. mi.                                      | 75.0<br>292.5<br>136.8<br>200.0<br>6 322.2          |
| Lander descent initiation                | 286.712              | 08/24/82       | 04:56:30              | Right ascension, deg<br>Declination, deg<br>True anomaly, deg<br>Impulsive $\Delta V$ , fps                                                                                              | 270<br>-47.5<br>180<br>128                          |

<sup>a</sup>Data given with reference to Earth or Venus is in planet-centered Earth equatorial coordinate system [(fig. 5 (a))]. Data given with reference to Mars is in Mars equatorial coordinate system [(fig. 5 (c))].

TABLE I.- SEQUENCE OF MAJOR EVENTS - Continued

| Event                             | Time, days<br>g.e.t. | Time           |                       | Data summary <sup>a</sup>                                                                                                                                        |
|-----------------------------------|----------------------|----------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                   |                      | Month/day/year | G.m.t.,<br>hr:min:sec |                                                                                                                                                                  |
| First aerobraking phase           | 286.867              | 08/24/82       | 08:39:59              | Duration, sec 320<br>Maximum dynamic pressure, psf 52.3<br>Maximum acceleration, ft/sec <sup>2</sup> 19.2<br>Velocity reduction, fps 3 100                       |
| Second aerobraking phase          | 286.499              | 08/24/82       | 23:49:55              | Duration, sec 478<br>Maximum dynamic pressure, psf 70.7<br>Maximum acceleration, ft/sec <sup>2</sup> 25.9<br>Velocity reduction, fps 7 700                       |
| Propulsive braking phase          | 286.505              | 08/24/82       | 23:57:53              | Initial altitude, ft 36 217<br>Initial velocity, fps 3 451<br>Flight-path angle, deg -17.0<br>Characteristic velocity, fps 3 769                                 |
| Landing site                      |                      |                |                       | Aerographic latitude, deg 69<br>Aerographic longitude, deg 130                                                                                                   |
| Lander ascent initiation          | 317.069              | 09/23/82       | 13:30:35              | Desired periapsis altitude, ft 300 000<br>Desired apoapsis altitude, n. mi. 100<br>Inclination, deg 75                                                           |
| Lander/spacecraft rendezvous      | 317.843              | 09/24/82       | 08:05:08              | Time required, hrs 18.5<br>Right ascension, deg 82.3<br>Declination, deg 46.3                                                                                    |
| Trans-Venus injection             | 346.551              | 10/23/82       | 01:04:05              | Right ascension, deg 52.3<br>Declination, deg 66.6<br>Geographic latitude, deg -24.7<br>Geographic longitude, deg 215.6<br>Impulsive velocity change, fps 12 929 |
| Mars sphere of influence (entry)  | 347.544              | 10/24/82       | 00:55:09              | Velocity, fps 21 941<br>Right ascension of velocity vector, deg 98.8<br>Declination of velocity vector, deg -28.8                                                |
| Venus sphere of influence (entry) | 472.827              | 02/26/83       | 07:42:49              | Velocity, fps 35 480<br>Right ascension of velocity vector, deg 202.8<br>Declination of velocity vector, deg -8.8                                                |

<sup>a</sup>Data given with reference to Earth or Venus is in planet-centered Earth equatorial coordinate system [(fig. 5 (a))]. Data given with reference to Mars is in Mars equatorial coordinate system [(fig. 5 (c))].

TABLE I.- SEQUENCE OF MAJOR EVENTS - Concluded

| Event                                | Time, days<br>g.e.t. | Time           |                       | Data summary <sup>a</sup>                                                                                                                                                |
|--------------------------------------|----------------------|----------------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                      |                      | Month/day/year | G.m.t.,<br>hr:min:sec |                                                                                                                                                                          |
| Periapsis at Venus<br>flyby          | 473.48               | 02/26/83       | 23:22:25              | Velocity, fps 43 520<br>Altitude, n. mi. 2 551<br>Right ascension, deg 136.3<br>Declination, deg 39.8<br>Geographic latitude, deg 1.2<br>Geographic longitude, deg 218.2 |
| Venus sphere of<br>influence (exit)  | 474.133              | 02/27/83       | 15:02:10              | Velocity, fps 35 480<br>Right ascension of velocity vector, deg 221.4<br>Declination of velocity vector, deg -24.6                                                       |
| Earth sphere of<br>influence (entry) | 640.199              | 08/12/83       | 00:58:19              | Velocity, fps 15 870<br>Right ascension of velocity vector, deg 225.8<br>Declination of velocity vector, deg -27.1                                                       |
| Earth entry                          | 642.309              | 08/14/83       | 03:35:43              | Velocity, fps 39 531<br>Geographic latitude, deg (south) -14.2<br>Geographic longitude, deg (west) 165.7                                                                 |

<sup>a</sup>Data given with reference to Earth or Venus is in planet-centered Earth equatorial coordinate system [(fig. 5 (a))]. Data given with reference to Mars is in Mars equatorial coordinate system [(fig. 5 (c))].

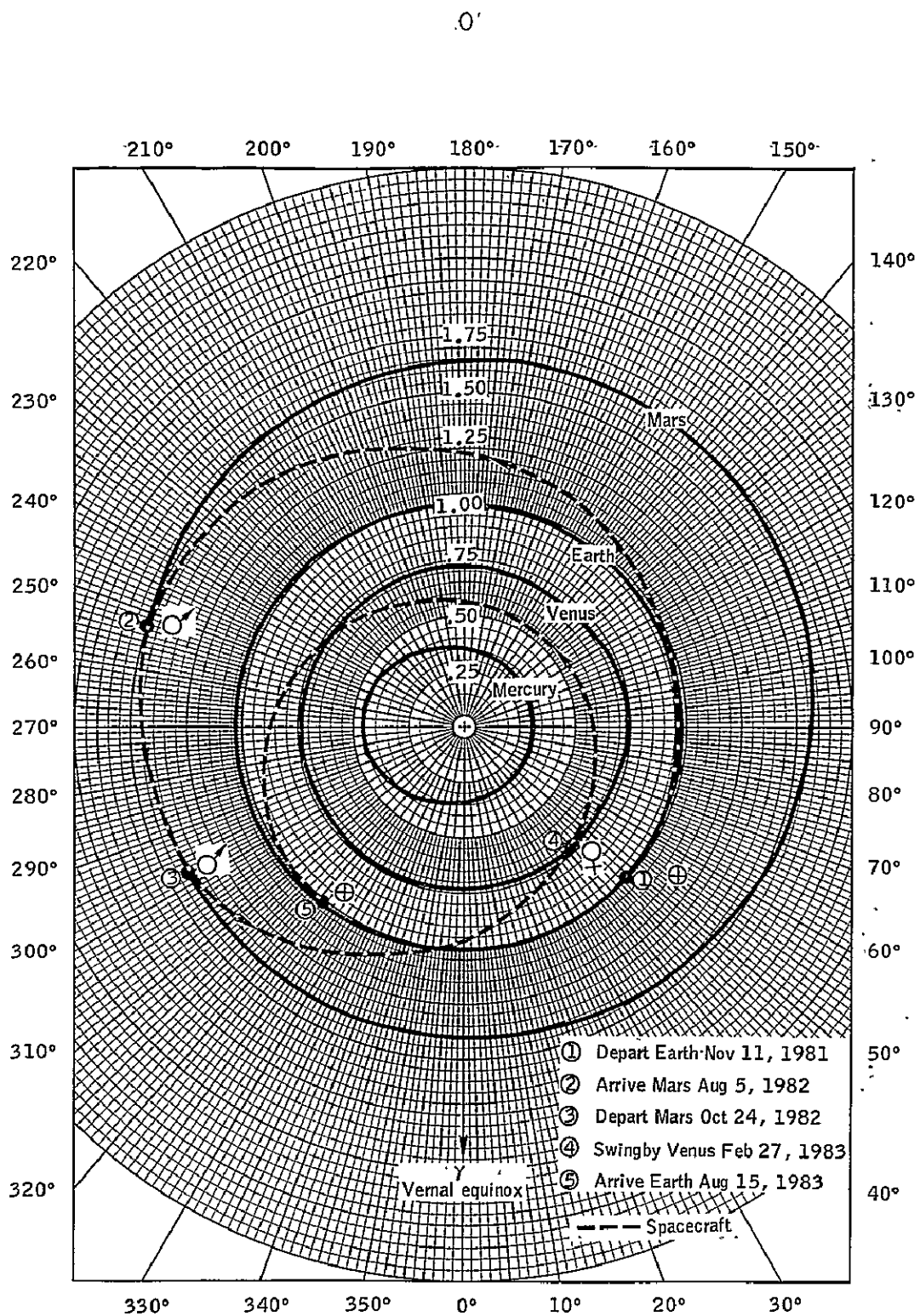


Figure 1.- Heliocentric view of 1981-80-day Mars stopover/Venus swingby mission.



## 5.0 EARTH BASED TRACKING SUMMARY

The tracking station inview time histories for the trans-Mars multiorbit injection phase are shown in figure 2. Twelve Earth-based tracking stations are listed along with the coverage they provide. Each of the eight thrusting maneuvers (indicated in fig. 2) is monitored at least partially by one or more of the tracking stations.

The inview time histories of the deep-space tracking stations (Goldstone, Woomera, and Madrid) are given in table II for all phases of the mission after trans-Mars injection except for the Mars orbit phase. Continuous coverage is possible with these three stations except for a brief period after entering the Earth SOI on the inbound trajectory.

The deep-space tracking stations inview time histories for the first, twentieth, fiftieth, and seventy-ninth day in orbit around Mars is given in table III. These times correspond to the approximate time of Mars orbit insertion, Mars lander descent, Mars lander ascent, and transearth injection, respectively. Continuous communication is possible except for brief periods when the spacecraft is occulted by Mars.

The time required for Earth/spacecraft one-way signal propagation (fig. 3) increases 10.9 minutes at Mars arrival. The signal propagation time at Mars departure is 14.5 minutes and at Venus periapsis is 11.9 minutes. The maximum time is 15.6 minutes.

The sun can adversely affect communications if it comes in proximity to the Earth/spacecraft line of sight. The Sun-Earth-spacecraft angle is shown in figure 4. The minimum angle is  $7.5^\circ$  and occurs during the Venus-to-Earth portion of the mission.

TABLE II.- DEEP SPACE TRACKING STATION INVIEW TIME HISTORIES - 1981 VENUS SWINGBY MISSION.

(a) TMI to ESOI

| Goldstone                                              |                                                       | Woomera                                 |                                         | Madrid                                  |                                        |
|--------------------------------------------------------|-------------------------------------------------------|-----------------------------------------|-----------------------------------------|-----------------------------------------|----------------------------------------|
| AOS, day:hr:min:sec                                    | LOS, day:hr:min:sec                                   | AOS, day:hr:min:sec                     | LOS, day:hr:min:sec                     | AOS, day:hr:min:sec                     | LOS, day:hr:min:sec                    |
| 00:00:19:57<br>00:22:49:09<br>1:22:46:54<br>2:22:43:36 | 00:10:42:56<br>1:11:05:09<br>2:11:06:54<br>3:11:05:33 | 00:06:43:19<br>1:07:00:35<br>2:07:00:12 | 00:16:57:17<br>1:17:03:06<br>2:17:02:04 | 00:15:14:24<br>1:15:12:13<br>2:15:08:51 | 1:03:37:56<br>2:03:42:26<br>3:03:41:51 |

(b) ESOI to MSOI

(Stations on sequentially with each station tracking period overlapping previous station approx 2-4 hr)

|                                                    |                                                    |                                                    |
|----------------------------------------------------|----------------------------------------------------|----------------------------------------------------|
| Continuous tracking approximately<br>13 hr per day | Continuous tracking approximately<br>10 hr per day | Continuous tracking approximately<br>12 hr per day |
|----------------------------------------------------|----------------------------------------------------|----------------------------------------------------|

(c) MSOI to MOI

|                              |              |                              |                              |                              |                              |
|------------------------------|--------------|------------------------------|------------------------------|------------------------------|------------------------------|
| 265:08:06:19<br>266:09:52:35 | 265:18:01:57 | 264:14:05:13<br>265:14:02:54 | 265:02:16:21<br>266:02:15:11 | 265:00:45:54<br>266:00:44:54 | 265:10:23:14<br>266:10:20:38 |
|------------------------------|--------------|------------------------------|------------------------------|------------------------------|------------------------------|

TABLE II.- DEEP SPACE TRACKING STATION INVIEW TIME HISTORIES - 1981 VENUS SWINGBY MISSION - CONTINUED.

(d) TEI to MSOI

| Goldstone                    |                              | Woomera                      |                     | Madrid              |                     |
|------------------------------|------------------------------|------------------------------|---------------------|---------------------|---------------------|
| AOS, day:hr:min:sec          | LOS, day:hr:min:sec          | AOS, day:hr:min:sec          | LOS, day:hr:min:sec | AOS, day:hr:min:sec | LOS, day:hr:min:sec |
| 346:13:12:51<br>347:05:44:38 | 346:14:19:32<br>347:14:02:42 | 346:13:12:51<br>347:10:16:11 | 346:23:32:38        | 346:22:24:17        | 347:06:13:38        |

(e) MSOI to VSOI

(Sequential tracking of stations and overlap periods approximately same as shown in part (b))

|                                                    |                                                    |                                                    |
|----------------------------------------------------|----------------------------------------------------|----------------------------------------------------|
| Continuous tracking approximately<br>11 hr per day | Continuous tracking approximately<br>13 hr per day | Continuous tracking approximately<br>10 hr per day |
|----------------------------------------------------|----------------------------------------------------|----------------------------------------------------|

(f) Within VSOI

|                              |                              |                              |                              |                              |                              |
|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| 472:02:31:18<br>473:02:38:16 | 472:13:58:23<br>473:13:57:41 | 472:09:49:52<br>473:09:49:47 | 472:20:56:21<br>473:20:55:22 | 472:19:09:35<br>473:19:08:08 | 473:06:26:14<br>474:05:27:44 |
|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|

TABLE II.- DEEP SPACE TRACKING STATION INVIEW TIME HISTORIES - 1981 VENUS SWINGBY MISSION - CONCLUDED.

(g) VS01 to ES01

|                                                    |                                                   |                                                    |
|----------------------------------------------------|---------------------------------------------------|----------------------------------------------------|
| Continuous tracking approximately<br>14 hr per day | Continuous tracking approximately<br>9 hr per day | Continuous tracking approximately<br>14 hr per day |
|----------------------------------------------------|---------------------------------------------------|----------------------------------------------------|

(h) ES01 to entry

| Goldstone                                    |                                              | Woomera                      |                              | Madrid                                       |                                              |
|----------------------------------------------|----------------------------------------------|------------------------------|------------------------------|----------------------------------------------|----------------------------------------------|
| AOS, day:hr:min:sec                          | LOS, day:hr:min:sec                          | AOS, day:hr:min:sec          | LOS, day:hr:min:sec          | AOS, day:hr:min:sec                          | LOS, day:hr:min:sec                          |
| 639:17:15:09<br>640:17:15:19<br>641:18:17:21 | 639:18:45:03<br>641:07:05:01<br>641:20:27:30 | 640:02:57:40<br>641:03:03:48 | 640:11:30:08<br>641:11:31:15 | 639:18:45:03<br>640:09:28:51<br>641:09:40:49 | 639:23:49:58<br>640:23:48:52<br>641:21:12:15 |

TABLE III.- DEEP SPACE TRACKING STATIONS INVIEW TIME HISTORIES FOR MARS ORBITAL PERIOD.

## (a) Day 1

| Goldstone                                            |                     | Woomera             |                     | Madrid              |                     |
|------------------------------------------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| AOS, day:hr:min:sec                                  | LOS, day:hr:min:sec | AOS, day:hr:min:sec | LOS, day:hr:min:sec | AOS, day:hr:min:sec | LOS, day:hr:min:sec |
| 266:13:12:51                                         |                     |                     |                     |                     |                     |
| Mars occulting vehicle: 266:13:13:45 to 266:13:51:37 |                     |                     |                     |                     |                     |
|                                                      | 266:17:59:28        | 266:14:00:36        |                     |                     |                     |
| Mars occulting vehicle: 266:21:00:57 to 266:21:36:15 |                     |                     |                     |                     |                     |
|                                                      |                     |                     | 267:02:13:47        | 267:00:43:56        |                     |
| Mars occulting vehicle: 267:04:42:59 to 267:05:20:53 |                     |                     |                     |                     |                     |
| 267:08:04:05                                         |                     |                     |                     |                     | 267:10:18:02        |
| Mars occulting vehicle: 267:12:27:36 to 267:13:05:31 |                     |                     |                     |                     |                     |

## (b) Day 20

|                                                      |              |              |              |              |              |
|------------------------------------------------------|--------------|--------------|--------------|--------------|--------------|
| 286:13:12:51                                         |              | 286:13:16:49 |              |              |              |
| Mars occulting vehicle: 286:13:17:46 to 286:13:52:43 |              |              |              |              |              |
|                                                      | 286:17:13:38 |              |              |              |              |
| Mars occulting vehicle: 286:21:02:18 to 286:21:37:14 |              |              |              |              |              |
|                                                      |              |              | 287:01:51:52 | 287:00:28:33 |              |
| Mars occulting vehicle: 287:04:46:57 to 287:05:21:44 |              |              |              |              |              |
| 287:07:45:49                                         |              |              |              |              | 287:09:34:05 |
| Mars occulting vehicle: 287:12:31:37 to 287:13:06:14 |              |              |              |              |              |

## (c) Day 50

|                              |              |                              |              |              |              |
|------------------------------|--------------|------------------------------|--------------|--------------|--------------|
| 316:13:12:51<br>317:07:27:31 | 316:16:17:41 | 316:13:12:51<br>317:12:26:21 | 317:01:28:00 | 317:00:14:26 | 317:08:29:37 |
|------------------------------|--------------|------------------------------|--------------|--------------|--------------|

## (d) Day 79

|                              |              |                              |              |              |              |
|------------------------------|--------------|------------------------------|--------------|--------------|--------------|
| 345:13:59:04<br>346:07:12:40 | 345:15:42:02 | 345:13:59:04<br>346:11:54:33 | 346:01:09:51 | 346:00:02:07 | 346:07:51:58 |
|------------------------------|--------------|------------------------------|--------------|--------------|--------------|

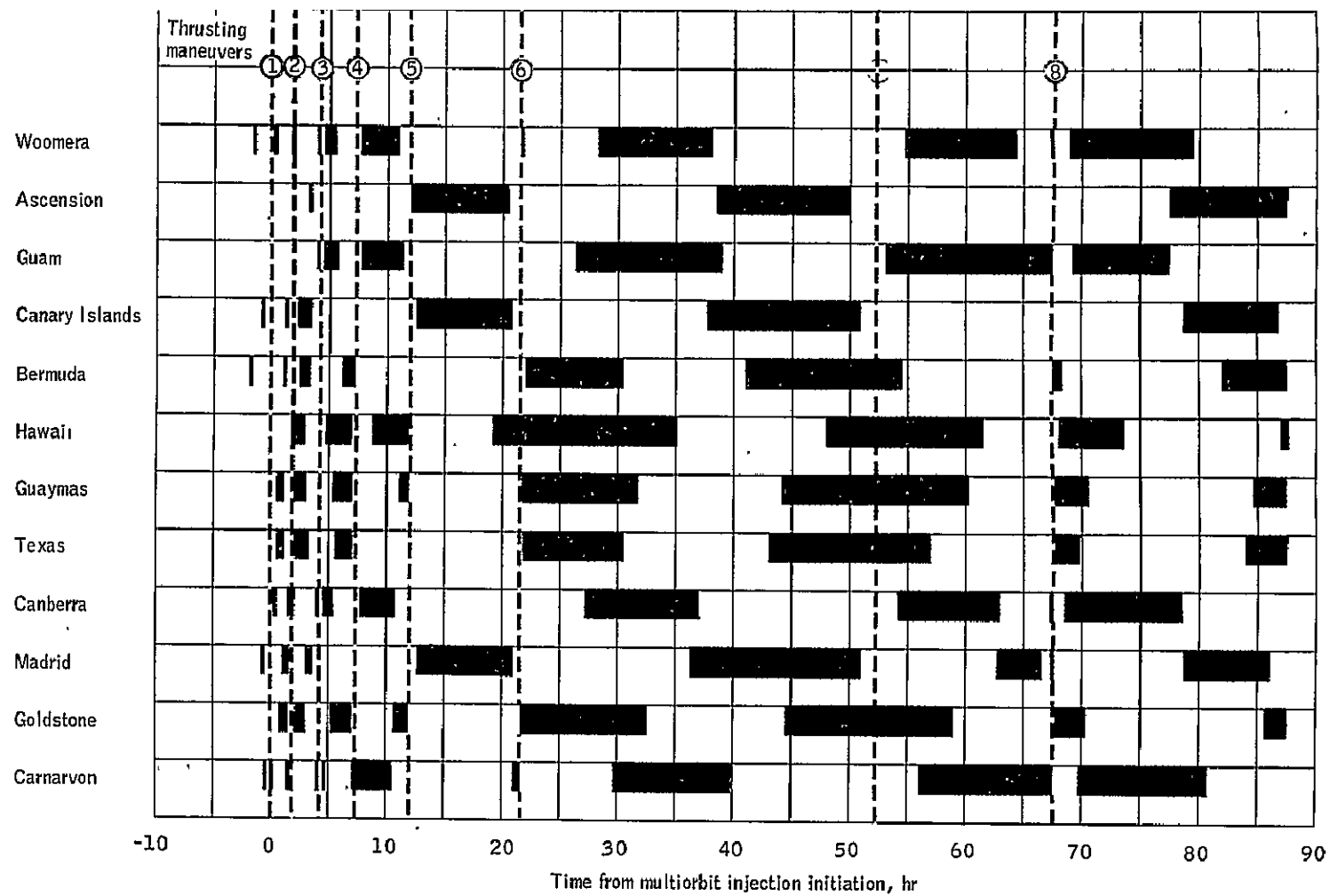


Figure 2.- Tracking station inview time histories for trans-Mars multiorbit injection phase..

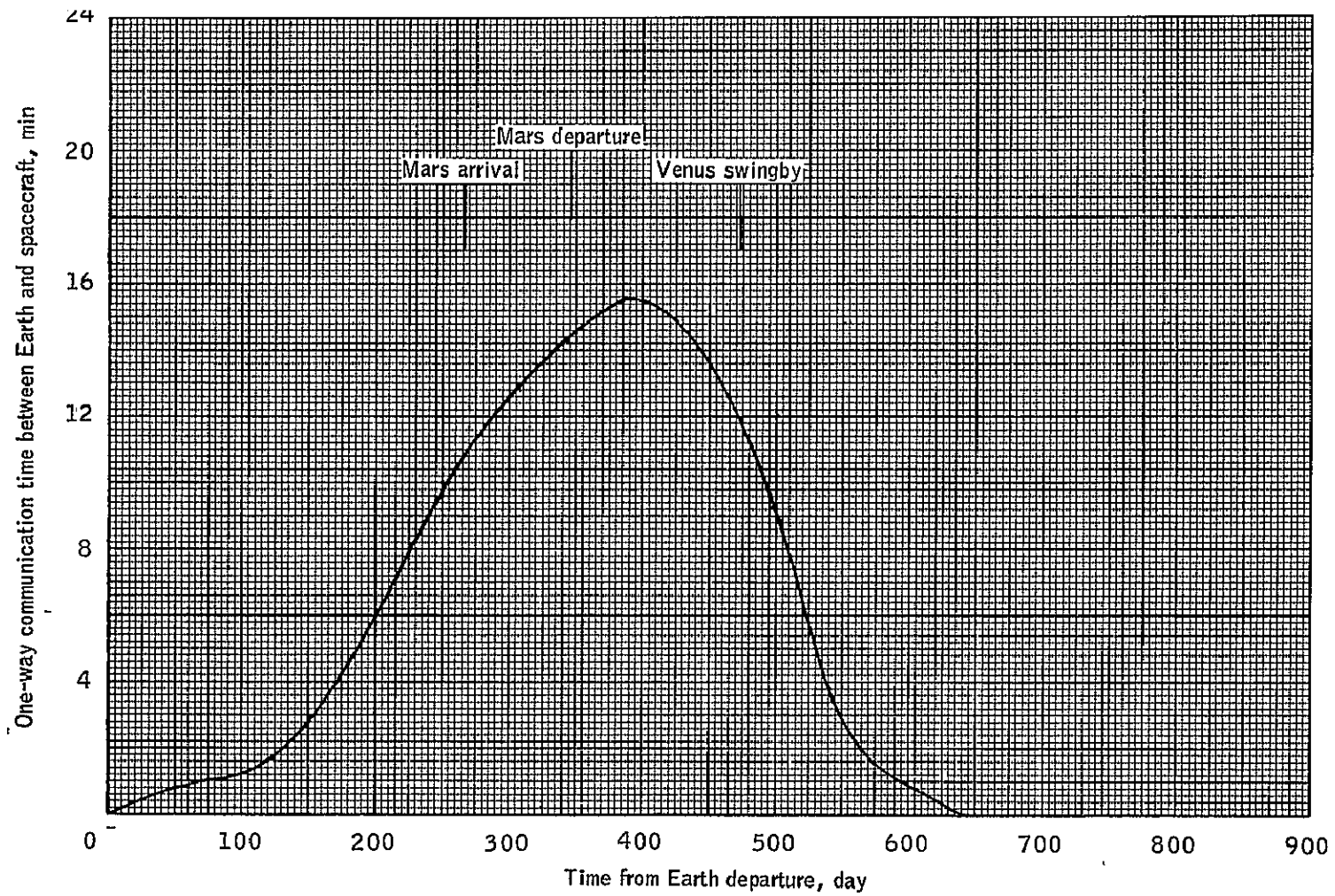


Figure 3.- Time required for Earth/spacecraft signal propagation, one-way.

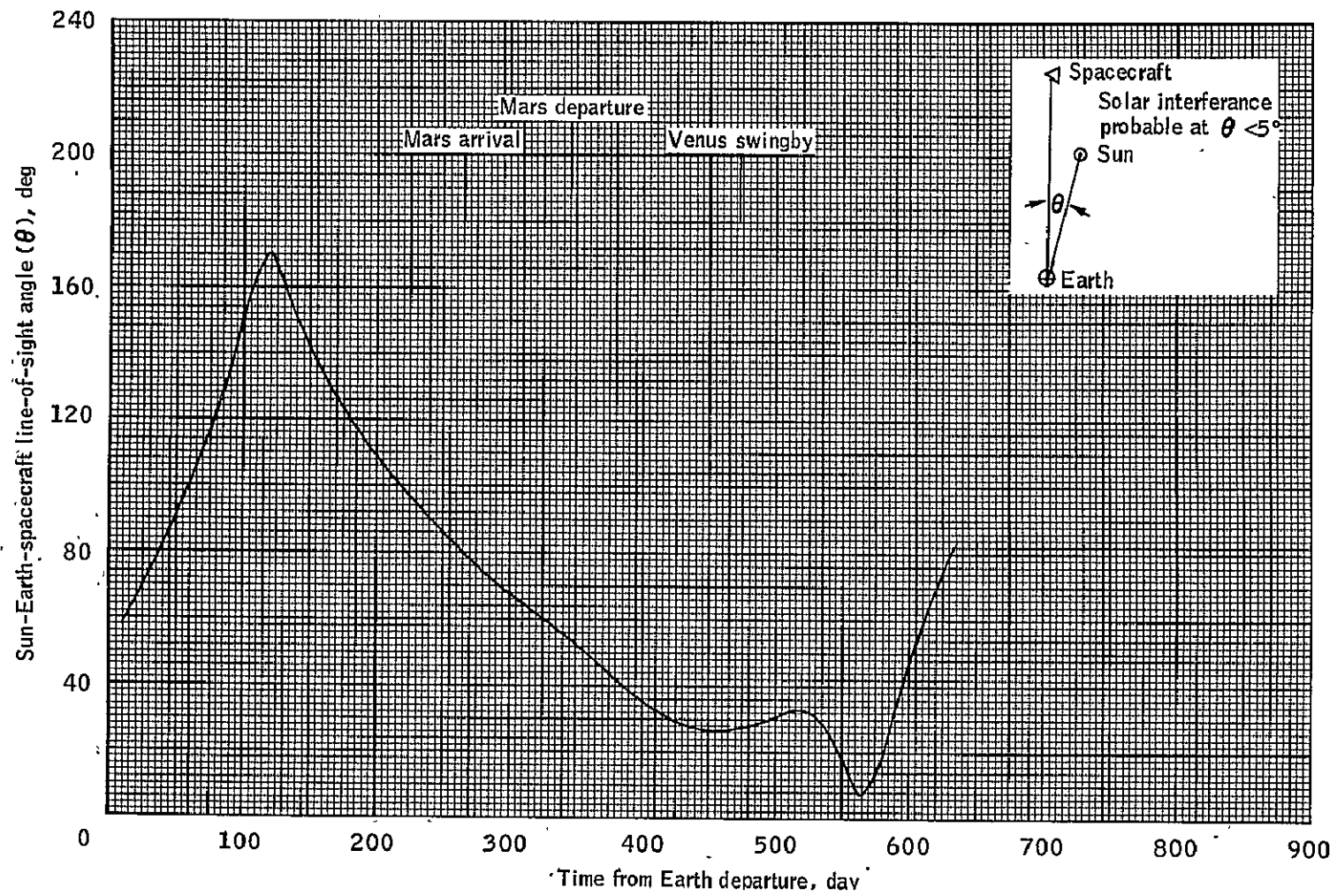


Figure 4.- Angle between the Sun and spacecraft lines of sight as viewed from the Earth.



## 6.0 DETAILED TRAJECTORY DESCRIPTION

A detailed description of each phase of the trajectory is presented in this section. Three different coordinate systems are used in the presentation of the data. All three systems are right-handed Cartesian systems. Inside the Earth and Venus spheres of influence, the planet-centered Earth equatorial system is used [fig. 5(a)]. The X-axis is in the direction of the vernal equinox (mean of date), and the principal plane is the Earth equatorial plane. In heliocentric space, the heliocentric ecliptic system is used [fig. 5(b)]. The X-axis is in the direction of the vernal equinox (mean of date), and the principal plane is the orbit plane of the Earth (the ecliptic). Inside the Mars sphere of influence, the coordinate system is the Mars equatorial system [fig. 5(c)]. The positive X-axis is defined by the intersection of the Mars orbit and equatorial planes and corresponds to the descending node of the Mars orbit on the equatorial plane (mean of date). The principal plane is the Mars equatorial plane.

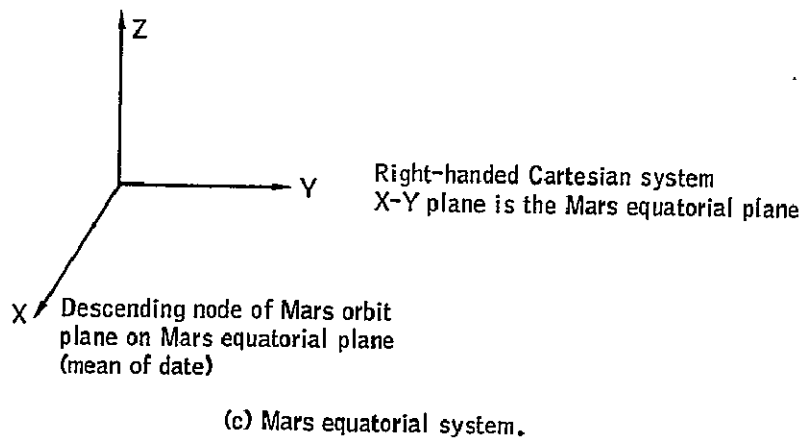
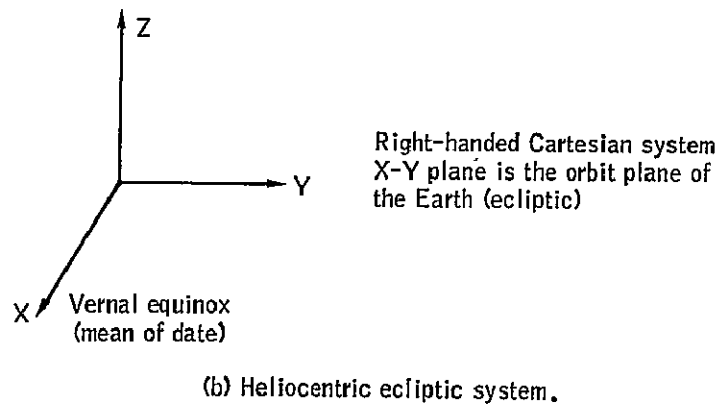
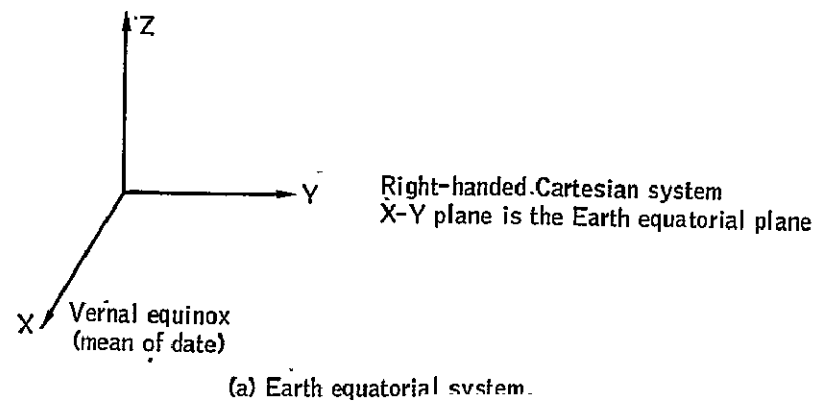


Figure 5.- Schematic of coordinate systems.

## 6.1 Earth Orbit Assembly

Assembly of the main spacecraft and the orbital launch vehicles (OLV) in Earth orbit is required for a manned interplanetary mission because of the tremendous weight involved. Depending on the time required for launch pad turnaround, assembly of the vehicles in Earth orbit, and checkout of the spacecraft systems, the first launch from Cape Kennedy must be made many weeks or perhaps months before the intended Earth departure date. In table IV, a launch schedule is shown for four launches from Cape Kennedy. The four launches are approximately 90 days apart to allow time for launch pad turnaround and possible OLV fueling by means of shuttle craft. The final launch occurs approximately 30 days prior to the final trans-Mars injection maneuver to allow time for spacecraft systems checkout and final preparations. The parking orbit is 260.33 n. mi. circular with an inclination of  $29.16^\circ$ . The launch azimuth is  $83.1219^\circ$ . This parking orbit was chosen because two direct rendezvous opportunities per day are possible with launches from Cape Kennedy (ref. 4). The right ascension of the ascending node  $\Omega$  of the parking orbit at the time of each launch is listed in table IV.

TABLE IV.- LAUNCH<sup>a</sup> SCHEDULE

| Launch<br>number | Date of launch |            | $\Delta t$ , <sup>b</sup><br>days | $\Omega$ ,<br>deg |
|------------------|----------------|------------|-----------------------------------|-------------------|
|                  | Mo/day/yr      | Hr:min:sec |                                   |                   |
| 1                | 1/14/1981      | 04:29:17   | 300.307                           | 42                |
| 2                | 4/14/1981      | 05:57:07   | 210.246                           | 153               |
| 3                | 7/13/1981      | 07:26:24   | 120.184                           | 263               |
| 4                | 10/11/1981     | 08:52:48   | 30.124                            | 14                |

<sup>a</sup>Inclination =  $29.16^\circ$ .

Altitude = 260.33 n. mi. circular.

Launch azimuth =  $83.1219^\circ$ .

<sup>b</sup>Time until final departure maneuver.

## 6.2 Trans-Mars Injection

A multiorbit injection technique that incorporates eight thrusting maneuvers and six revolutions around the Earth is used for trans-Mars injection. The technique is schematically illustrated in figure 6. The first six maneuvers are made at perigee and increase the apogee altitude of the parking orbit. The seventh maneuver is made near apogee and rotates the orbital plane such that it contains the Earth departure asymptote. The eighth maneuver is made at perigee and gives the vehicle the hyperbolic speed required for Earth departure.

The number and sizes (i.e., apogee/perigee radii) of the intermediate orbits were determined by a two-dimensional, finite thrust optimization program which accounted for propulsive losses and NERVA engine cooldown requirements (refs. 3, 4, and 5). The techniques discussed in references 6 and 7 were then used for computation of the actual departure sequence. Those techniques (refs. 6 and 7) are based on impulsive maneuvers but include three-dimensional effects as well as nodal and apsidal rotation rates.

The departure sequence is summarized in table V. The altitude of perigee stays constant at 260.33 n. mi., but the altitude of apogee increases with each revolution to a maximum of 63 238 n. mi. The period of the final orbit is 46 hours. The inclination of the parking orbit, until the time of the seventh maneuver, is  $29.16^\circ$ . The inclination of the final orbit and departure hyperbola is  $27.133^\circ$ . The elapsed time from the first maneuver to the last maneuver is 67.51 hours, and during this period the  $\Delta V$  required is 13 253 fps. This  $\Delta V$  requirement includes the 594 fps for cooldown losses for the nuclear propulsion injection stages and 280 fps for other propulsion losses.

A time history of the departure hyperbola is given in table VI and in figure 7 using the Earth-equatorial coordinate system. The spacecraft travel time from perigee to the Earth SOI is 66.0124 hours. The velocity at the Earth SOI is 11 855 fps, and the flight-path angle is  $88.667^\circ$ . The Earth groundtrack of the departure hyperbola is shown in figure 8. The position of each thrusting maneuver is also indicated. The geographic latitude and longitude of the final TMI maneuver are  $-24.75^\circ$  and  $174.82^\circ$ , respectively.

TABLE V.- SUMMARY OF EARTH DEPARTURE SEQUENCE

| Event     | Time<br>month/day<br>hr:min sec | $\Delta t$ ,<br>hr | Geographic<br>latitude,<br>deg | Geographic<br>longitude,<br>deg | $\Delta V$ , fps |                     |                      |                       | Time<br>relative to<br>event | $h_a^a$ ,<br>n. mi. | Period,<br>hr | $i$ ,<br>deg | $\Omega$ ,<br>deg | $\omega$ ,<br>deg |
|-----------|---------------------------------|--------------------|--------------------------------|---------------------------------|------------------|---------------------|----------------------|-----------------------|------------------------------|---------------------|---------------|--------------|-------------------|-------------------|
|           |                                 |                    |                                |                                 | Impulsive        | Cool-down<br>losses | Propulsive<br>losses | Total<br>accumulative |                              |                     |               |              |                   |                   |
| Impulse 1 | Nov. 7,<br>16:20:28             | -67.5118           | -23.303                        | 109.572                         | 1275             | 61                  | 12                   | 1 348                 | Before                       | 260.33              | 1.5708        | 29.160       | 170.941           | --                |
|           |                                 |                    |                                |                                 |                  |                     |                      |                       | After                        | 1 125.47            | 1.8538        | 29.160       | 170.941           | -125.720          |
| Impulse 2 | Nov. 7,<br>17 42 49             | -65.6594           | -23.482                        | 81.951                          | 1450             | 68                  | 19                   | 2 885                 | Before                       | 1 125.47            | 1 8538        | 29.160       | 170.579           | -125.136          |
|           |                                 |                    |                                |                                 |                  |                     |                      |                       | After                        | 2 470.78            | 2 3239        | 29.160       | 170.579           | -125.136          |
| Impulse 3 | Nov. 7,<br>20.30.58             | -63.3368           | -23.625                        | 47.215                          | 1536             | 74                  | 25                   | 4 520                 | Before                       | 2 470.78            | 2.3239        | 29.160       | 170.287           | -124.666          |
|           |                                 |                    |                                |                                 |                  |                     |                      |                       | After                        | 4 607.59            | 3 1398        | 29.160       | 170 287           | -124.666          |
| Impulse 4 | Nov. 7,<br>23 39.17             | -60.1984           | -23.740                        | .169                            | 1574             | 73                  | 31                   | 6 198                 | Before                       | 4 607.59            | 3.1398        | 29.160       | 170.051           | -124.286          |
|           |                                 |                    |                                |                                 |                  |                     |                      |                       | After                        | 8 321.20            | 4.7395        | 29.160       | 170 051           | -124.286          |
| Impulse 5 | Nov. 8,<br>04.23:33             | -55.4605           | -23.832                        | -70.965                         | 1745             | 87                  | 37                   | 8 067                 | Before                       | 8 321.20            | 4.7395        | 29.160       | 169.860           | -123.979          |
|           |                                 |                    |                                |                                 |                  |                     |                      |                       | After                        | 17 388.9            | 9.4680        | 29.160       | 169 860           | -123.979          |
| Impulse 6 | Nov. 8,<br>13:51:30             | -45.9946           | -23.905                        | 146.763                         | 1836             | 92                  | 40                   | 10 035                | Before                       | 17 388.9            | 9.4680        | 29.160       | 169.707           | -123.732          |
|           |                                 |                    |                                |                                 |                  |                     |                      |                       | After                        | 63 238.3            | 46 000        | 29.160       | 169.707           | -123.732          |
| Impulse 7 | Nov. 9,<br>20:42 32             | -15.1442           | +26.083                        | -128.619                        | 210              | 10                  | 0                    | 10 255                | Before                       | 63 238.3            | 46 000        | 29.160       | 169.624           | -123.599          |
|           |                                 |                    |                                |                                 |                  |                     |                      |                       | After                        | 63 238.3            | 46.000        | 27 133       | 158.098           | -113.426          |
| Impulse 8 | Nov. 10,<br>11:51.11            | 0.0                | -24.752                        | 174.820                         | 2753             | 129                 | 116                  | 13 253                | Before                       | 63 238.3            | 46 000        | 27.133       | 158 057           | -113.358          |
|           |                                 |                    |                                |                                 |                  |                     |                      |                       | After                        | --                  | --            | 27.133       | 158.057           | -113.358          |

<sup>a</sup>Altitude of perigee is 260.33 n. mi.ORIGINAL PAGE IS  
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TABLE VI.- TIME HISTORY OF EARTH DEPARTURE HYPERBOLA<sup>a</sup>

| Date,<br>November<br>day/hr:min:sec | $\Delta t$ , <sup>b</sup><br>hr | Altitude,<br>n. mi. | Velocity,<br>fps | Flight-path<br>angle,<br>deg | Right<br>ascension,<br>deg | Declination,<br>deg | Geographic<br>longitude,<br>deg | Azimuth,<br>deg | True<br>anomaly,<br>deg |
|-------------------------------------|---------------------------------|---------------------|------------------|------------------------------|----------------------------|---------------------|---------------------------------|-----------------|-------------------------|
| 10/11:51:11                         | 0.00                            | 260.33              | 37 176.5         | 0.000                        | 42.171                     | -24.752             | 174.821                         | 101.485         | 0.000                   |
| 10/12:06:11                         | .25                             | 1 968.50            | 31 421.8         | 35.929                       | 112.972                    | -19.946             | 241.862                         | 71.215          | 64.941                  |
| 10/12:21:11                         | .50                             | 4 911.12            | 26 188.3         | 50.995                       | 137.914                    | -10.008             | 263.044                         | 64.649          | 90.958                  |
| 10/12:51:11                         | 1.00                            | 10 771.2            | 21 382.5         | 63.060                       | 155.532                    | -1.293              | 273.141                         | 62.895          | 110.522                 |
| 10/13:51:11                         | 2.00                            | 21 368.8            | 17 832.5         | 71.867                       | 167.220                    | 4.665               | 269.788                         | 63.241          | 123.631                 |
| 10/14:51:11                         | 3.00                            | 31 040.3            | 16 298.1         | 75.817                       | 172.116                    | 7.096               | 259.643                         | 63.743          | 129.074                 |
| 10/16:51:11                         | 5.00                            | 48 957.0            | 14 821.8         | 79.787                       | 176.791                    | 9.347               | 234.236                         | 64.412          | 134.219                 |
| 10/21:51:11                         | 10.00                           | 90 039.6            | 13 447.2         | 83.711                       | 181.144                    | 11.362              | 163.384                         | 65.195          | 138.951                 |
| 11/02:51:11                         | 15.00                           | 128 792.9           | 12 895.8         | 85.368                       | 182.895                    | 12.148              | 89.929                          | 65.552          | 140.838                 |
| 11/07:51:11                         | 20.00                           | 166 409.1           | 12 591.4         | 86.308                       | 183.865                    | 12.577              | 15.694                          | 65.759          | 141.877                 |
| 11/12:51:11                         | 25.00                           | 203 338.3           | 12 396.4         | 86.920                       | 184.487                    | 12.849              | 301.111                         | 65.896          | 142.543                 |
| 11/17:51:11                         | 30.00                           | 239 803.6           | 12 260.2         | 87.353                       | 184.922                    | 13.039              | 226.340                         | 65.994          | 143.007                 |
| 12/03:51:11                         | 40.00                           | 311 807.8           | 12 081.4         | 87.928                       | 185.494                    | 13.286              | 76.502                          | 66.124          | 143.616                 |
| 12/13:51:11                         | 50.00                           | 382 993.9           | 11 968.9         | 88.294                       | 185.855                    | 13.441              | 286.452                         | 66.207          | 144.000                 |
| 12/23:51:11                         | 60.00                           | 453 637.7           | 11 891.2         | 88.548                       | 186.104                    | 13.548              | 136.290                         | 66.265          | 144.265                 |
| <sup>c</sup> 13/05:51:55            | 66.0124                         | 495 918.7           | 11 855.1         | 88.667                       | 186.220                    | 13.597              | 45.974                          | 66.292          | 144.388                 |

<sup>a</sup>Inclination = 27.133°.<sup>b</sup>Time after final departure maneuver.<sup>c</sup>Earth SOI.ORIGINAL PAGE IS  
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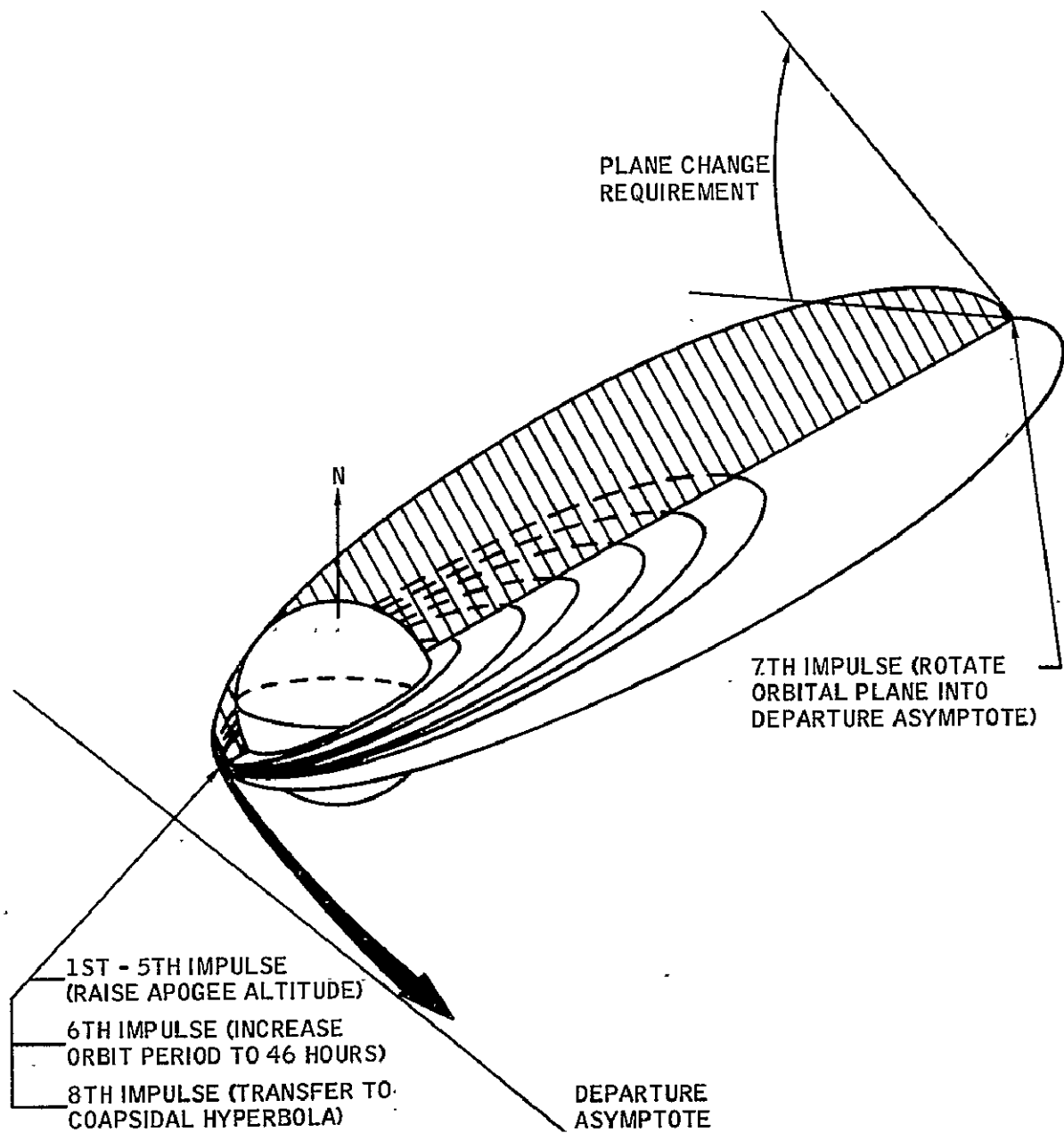
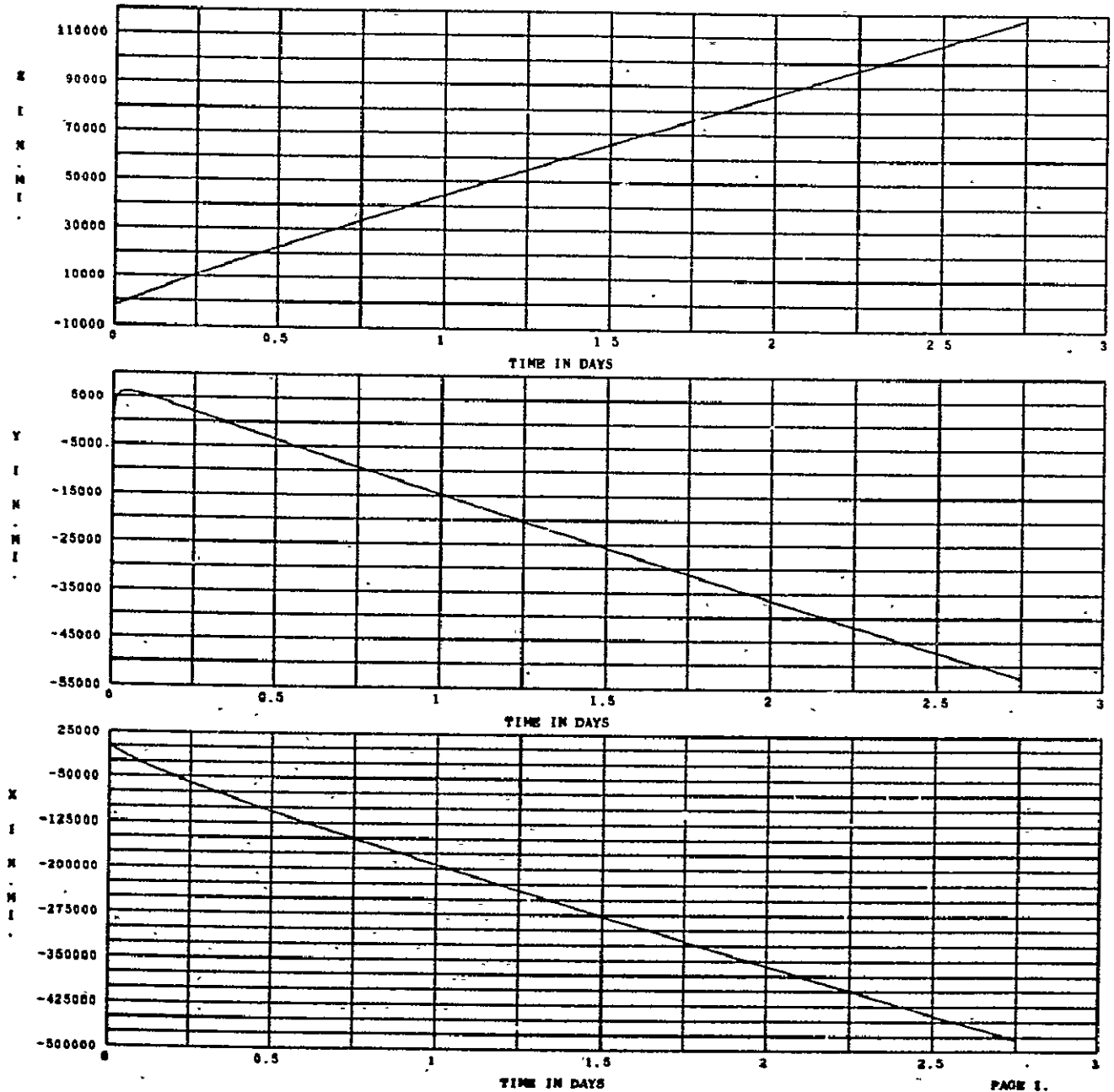


Figure 6.- Geometry of eight-impulse planetary departure.

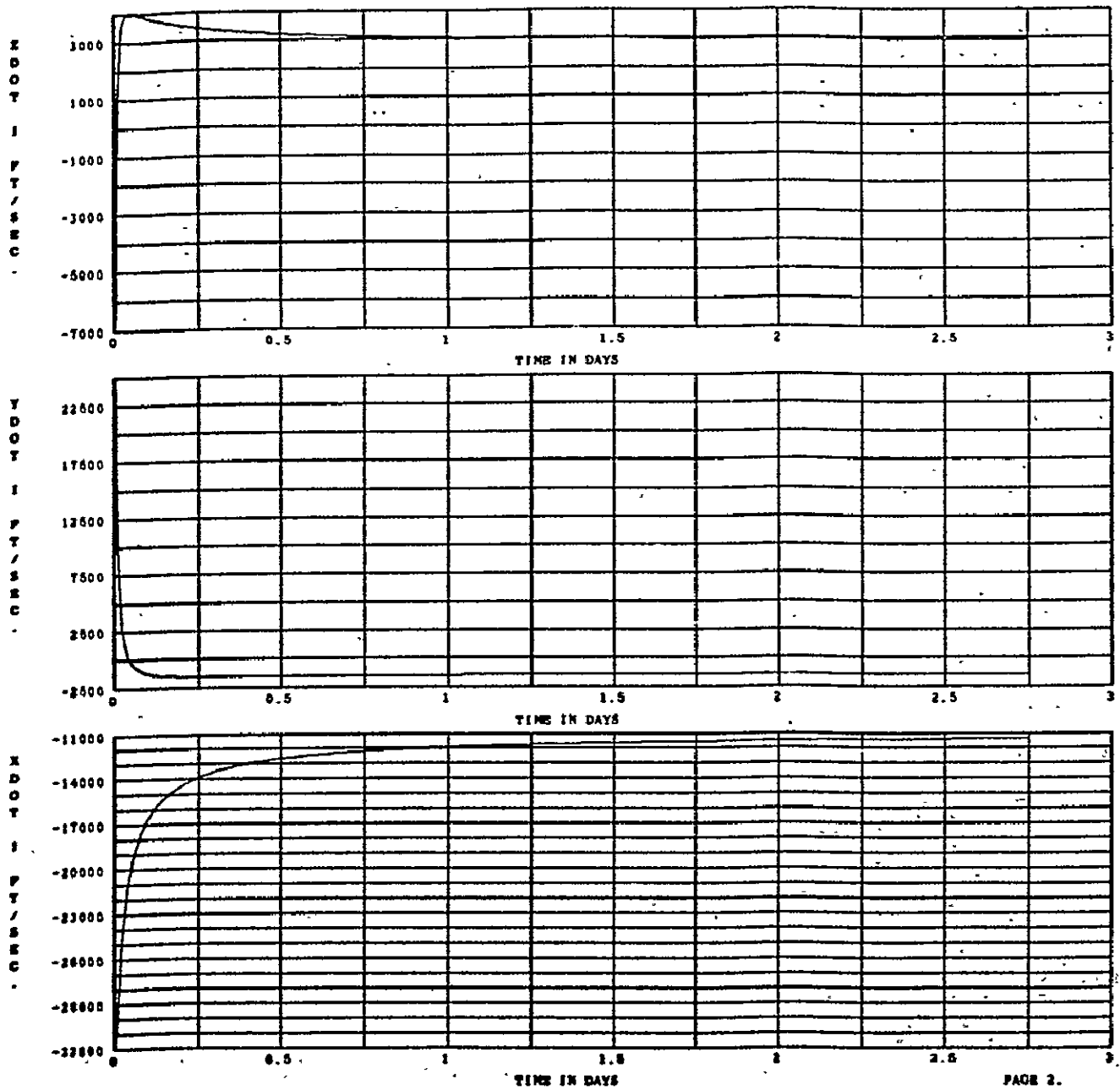


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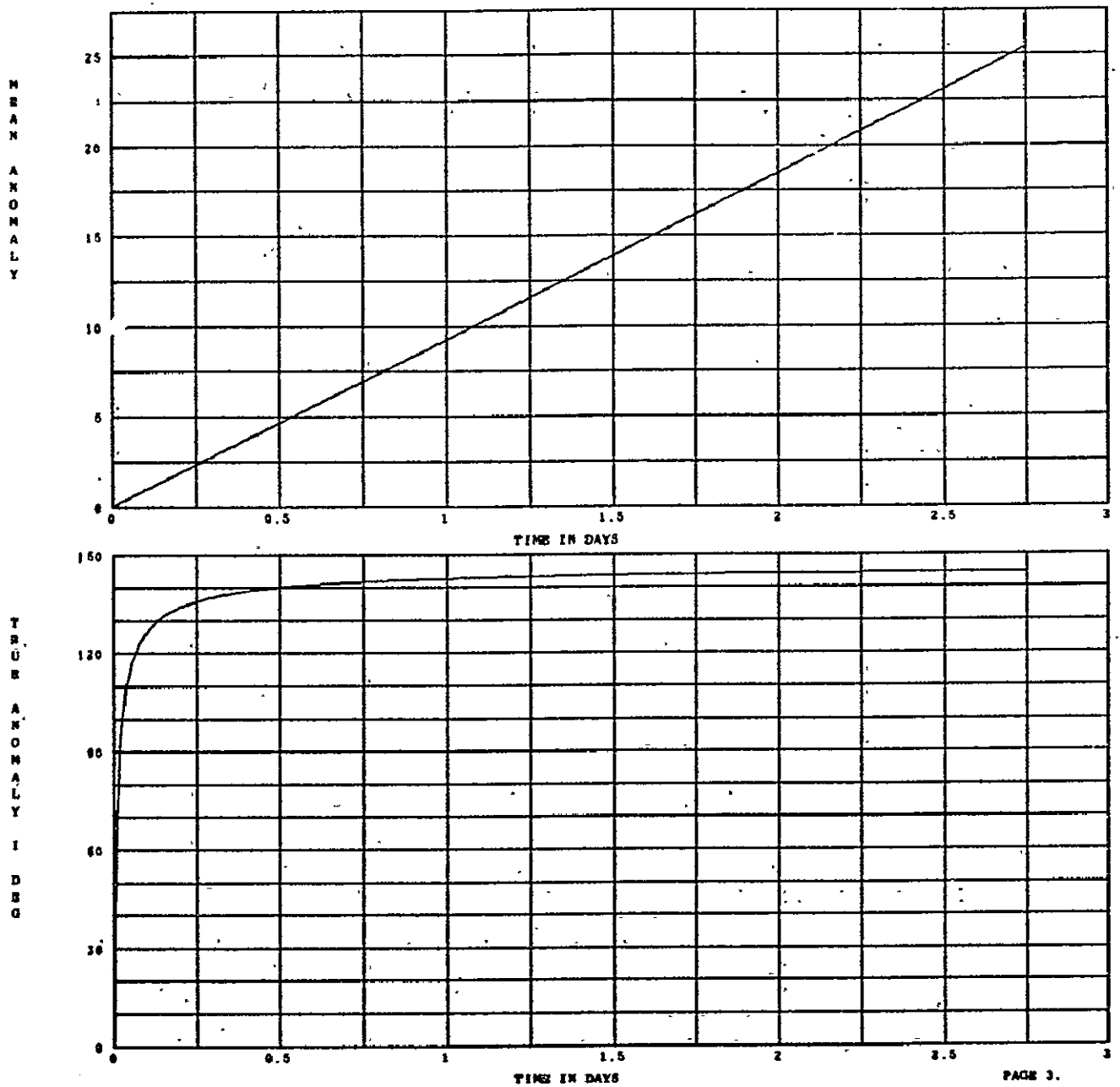
(a) Time histories of the Cartesian components of the position vector.

Figure 7.- Earth departure trajectory parameters (planetocentric equatorial coordinate system) periapsis to sphere of influence.



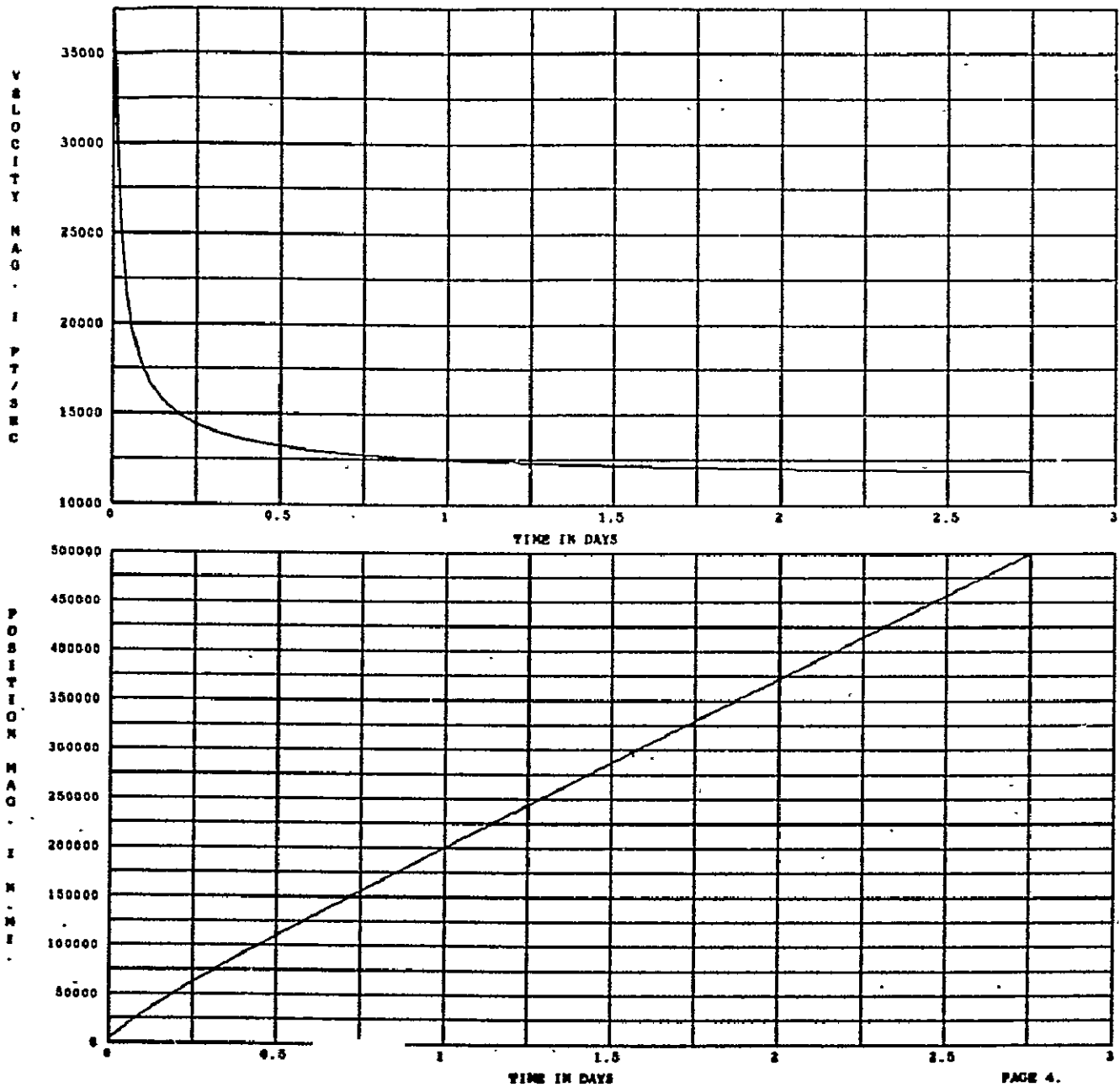
(b) Time histories of the Cartesian components of the velocity vector.

Figure 7.- Continued.



(c) Time histories of the true anomaly and mean anomaly.

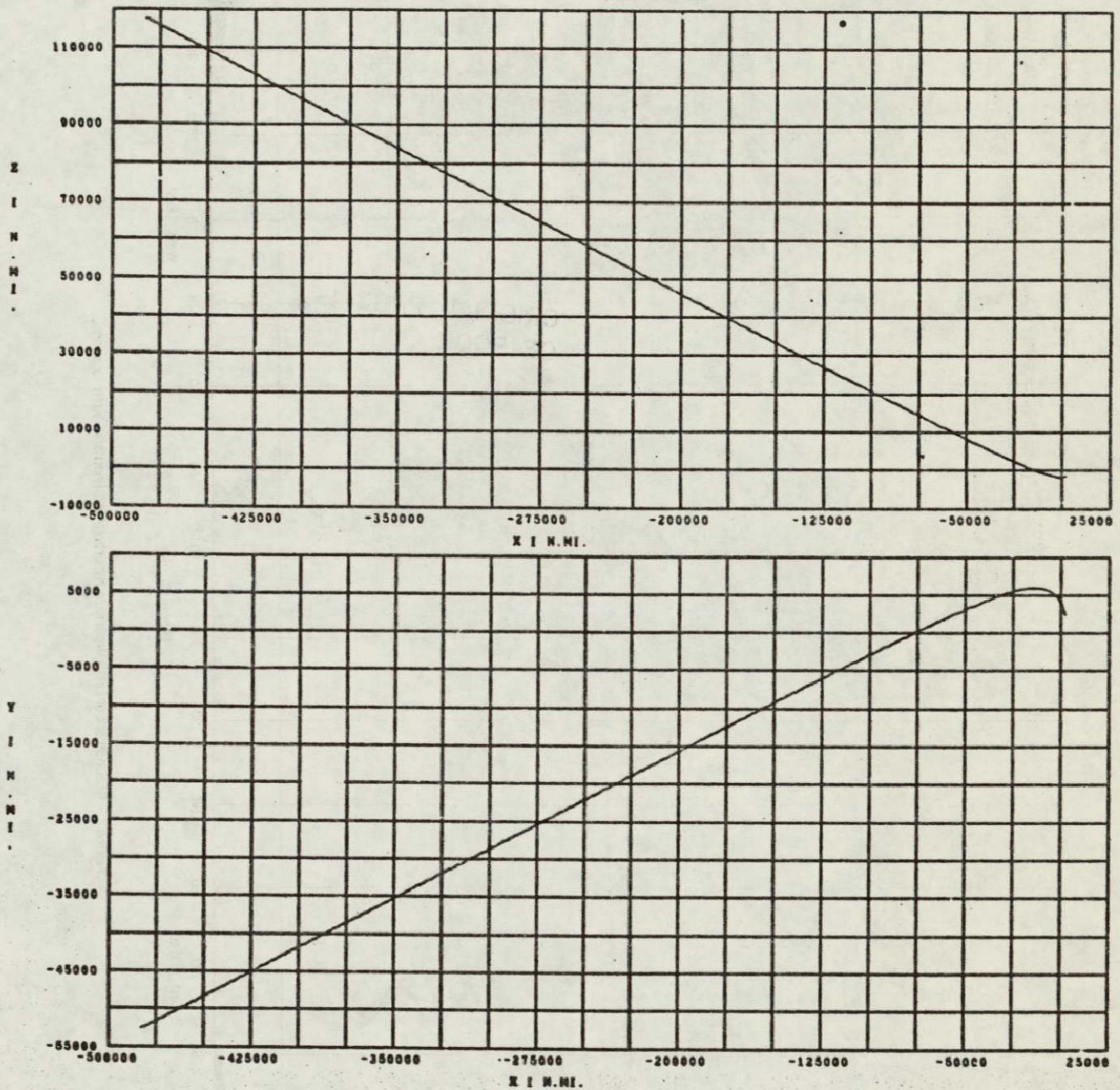
Figure 7.—Continued.



PAGE 4.

(d) Time histories of the magnitudes of the position and velocity vectors.

Figure 7.- Continued.

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(e) Trajectory projections on the X-Y and X-Z planes.

Figure 7.- Concluded.



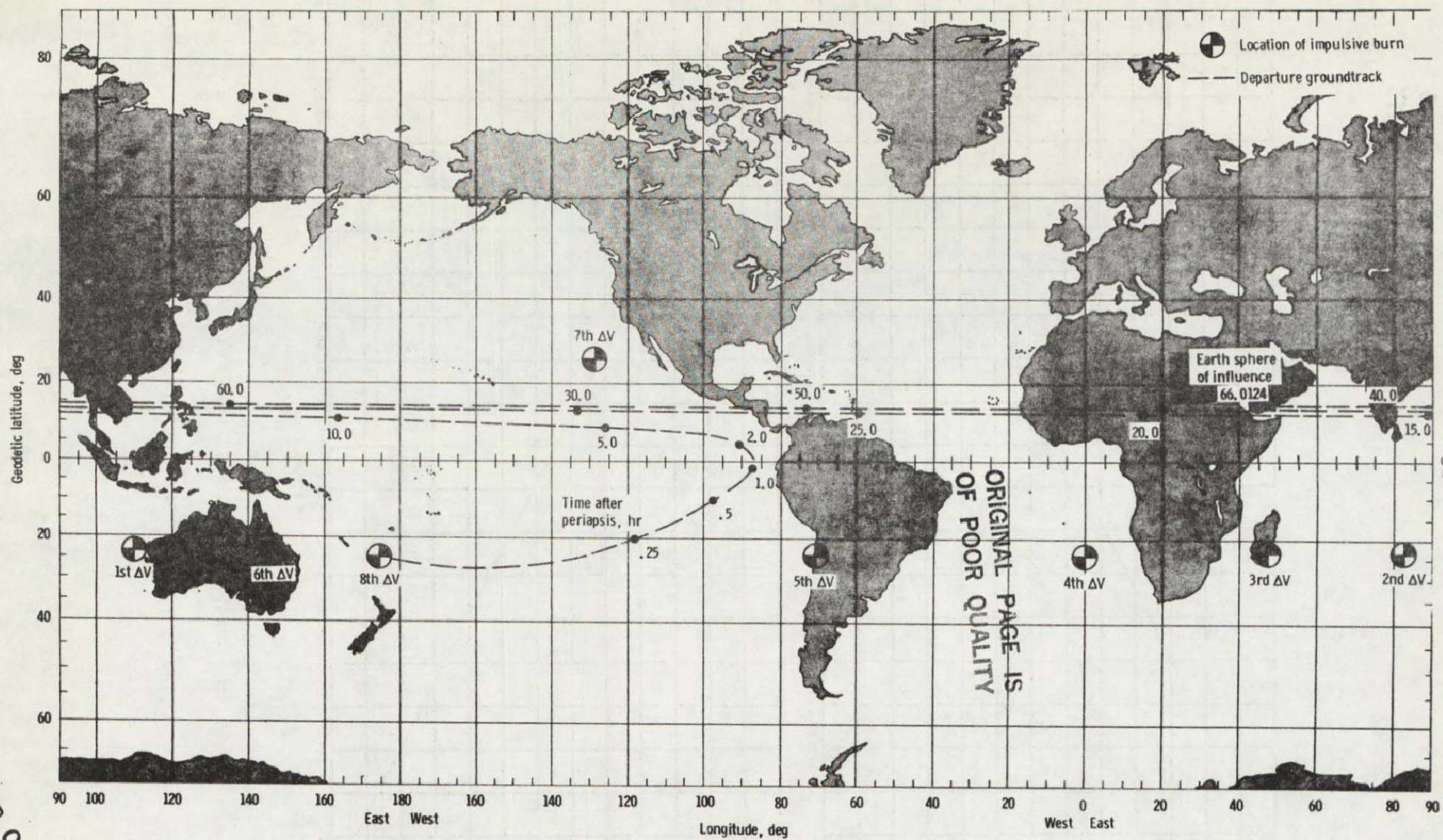
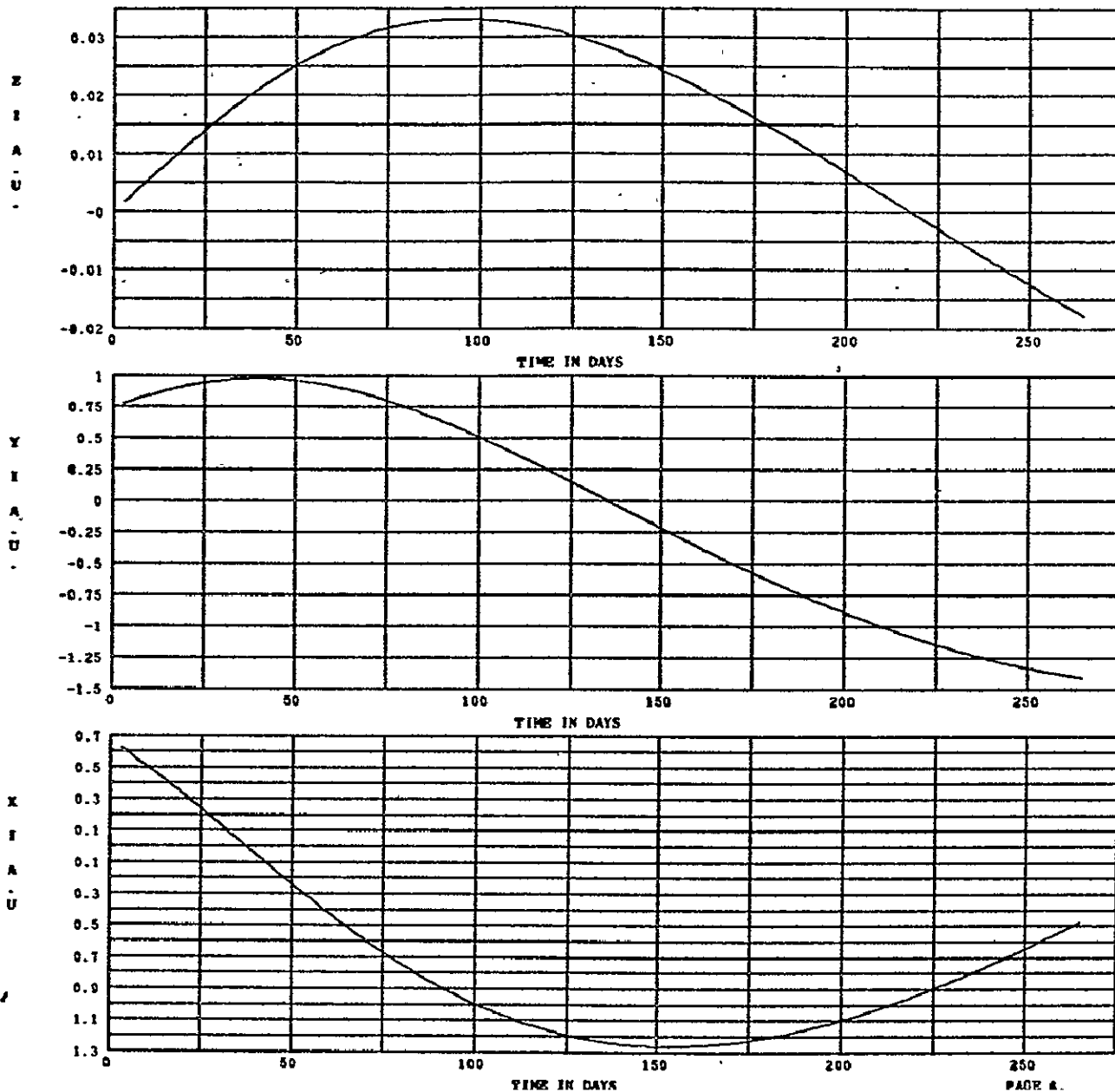


Figure 8. - Groundtrack of Earth departure hyperbola and impulsive burn locations.

### 6.3 Earth-to-Mars Coast

A time history of trajectory parameters for the Earth-to-Mars coast (Earth SOI to Mars SOI) is shown in figure 9. The heliocentric ecliptic coordinate system is used for this phase of the mission. The heliocentric transfer angle is approximately  $200^\circ$ , and the transfer time is 262 days. The eccentricity and inclination of the transfer orbit are  $0.2136^\circ$  and  $1.7429^\circ$  respectively. The spacecraft distances to the inner planets and the Sun are shown in figure 10 for the entire mission. In the Earth-to-Mars portion of the mission, the closest approach to Venus is approximately one-third A.U., while the closest approach to Mercury is approximately three-fourths A.U. The spacecraft/Earth distance at the time of spacecraft arrival at Mars is 1.3 A.U. The spacecraft varies in distance from the Sun from approximately 1 to 1.5 A.U. during the Earth-to-Mars coast.



(a) Time histories of the Cartesian components of the position vector.

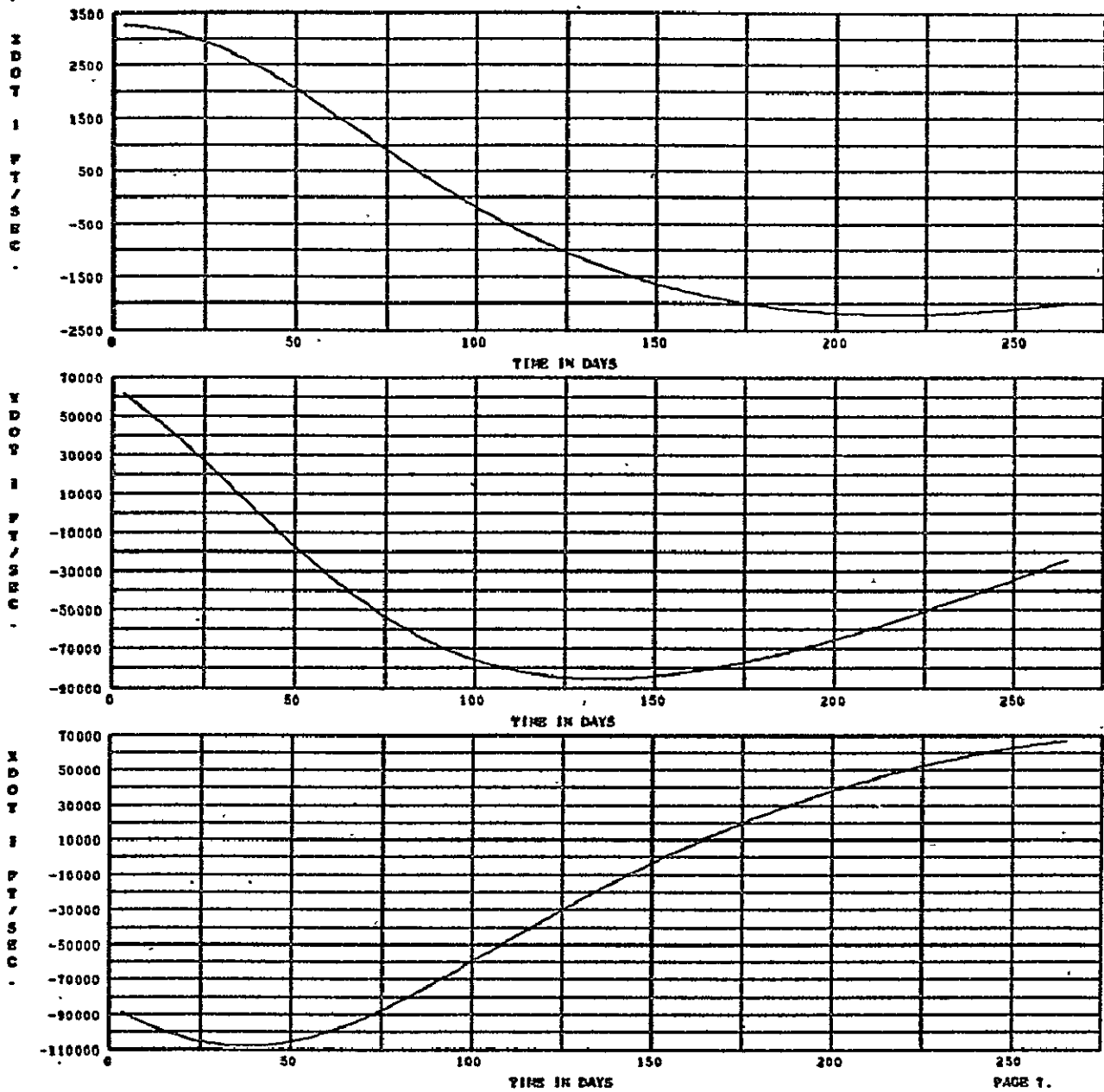
Figure 9.- Earth-to-Mars trajectory parameters (heliocentric ecliptic coordinate system) connecting spheres of influence boundaries.

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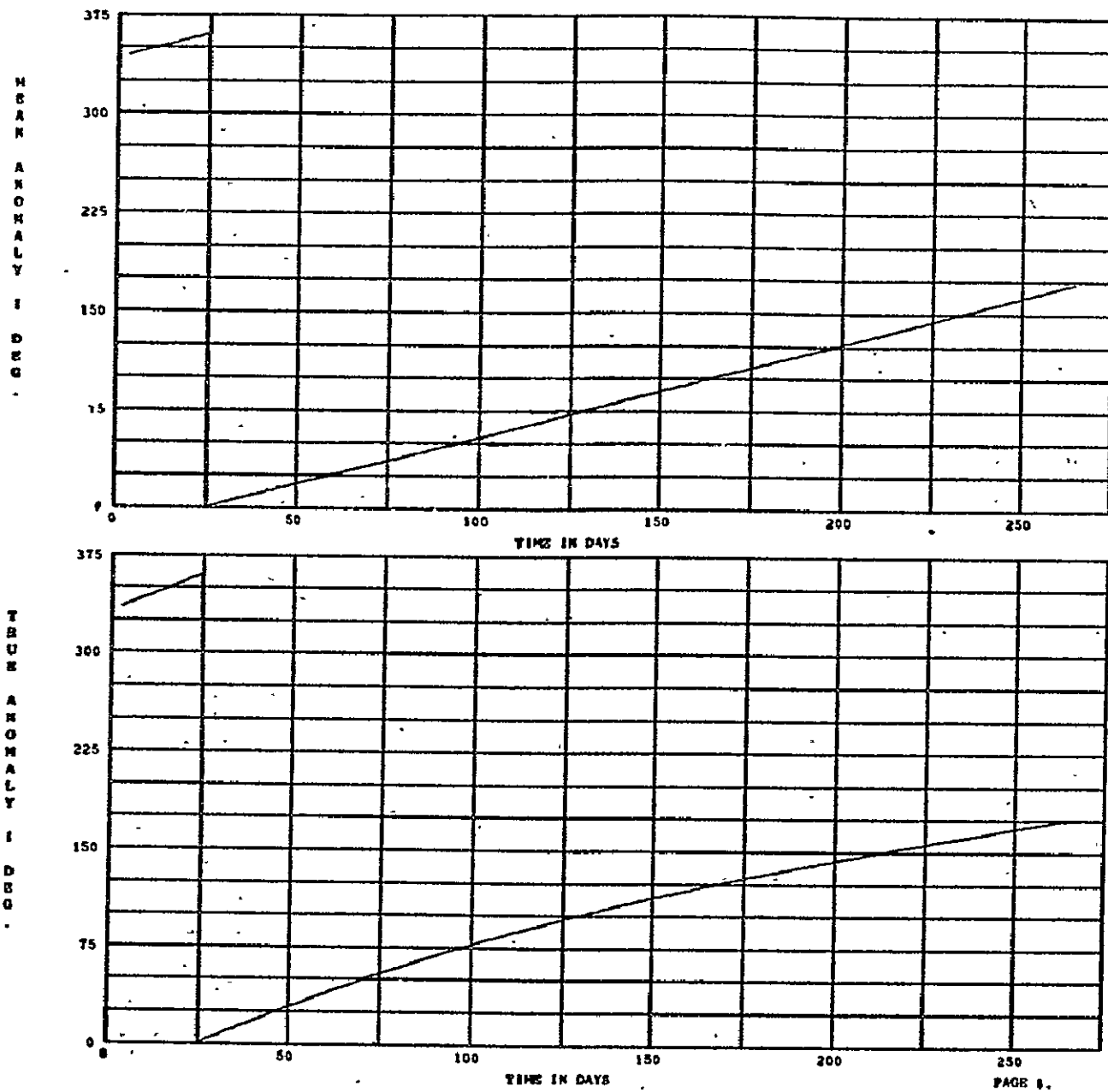
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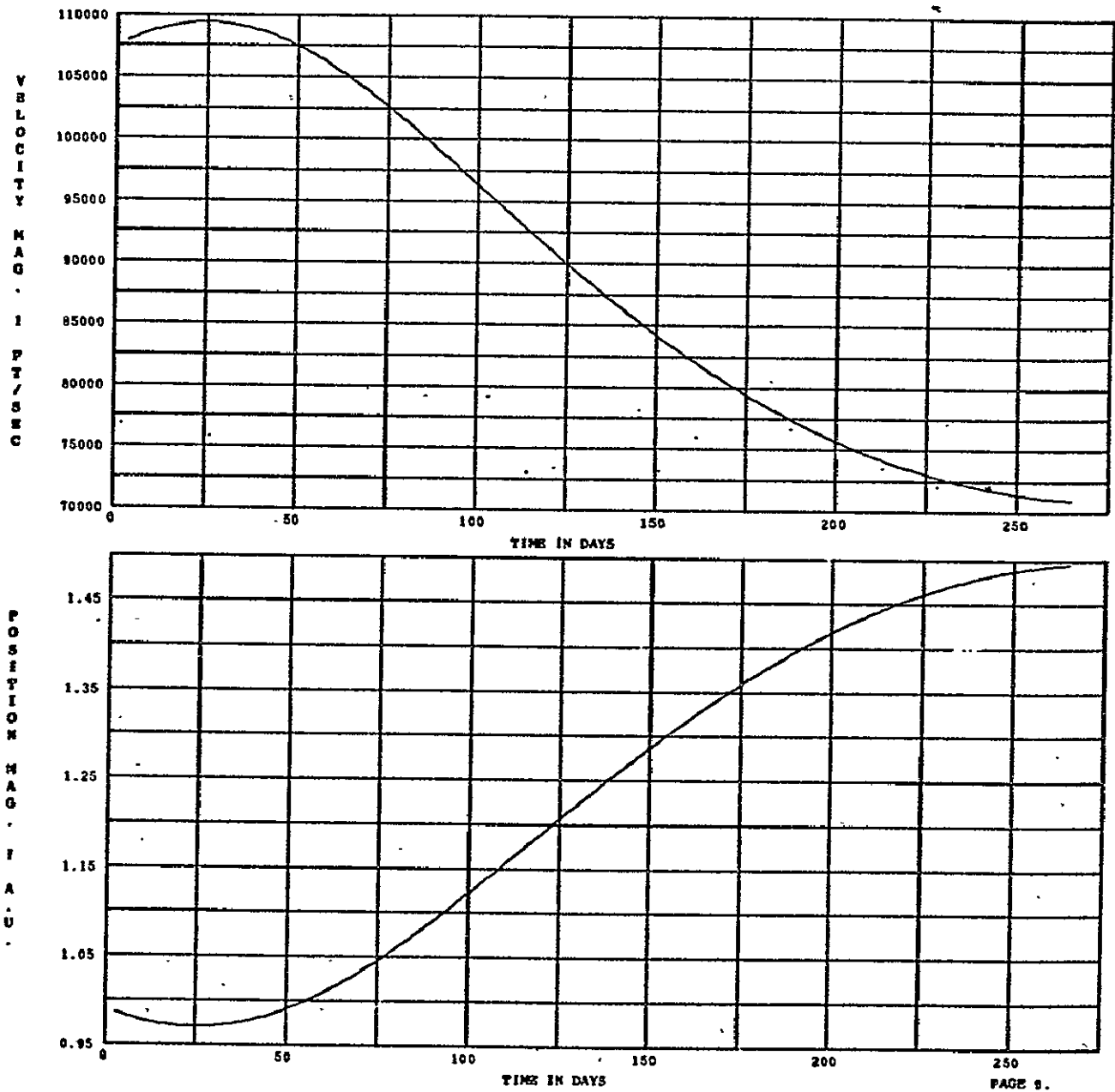
(b) Time histories of the Cartesian components of the velocity vector.

Figure 9.- Continued.



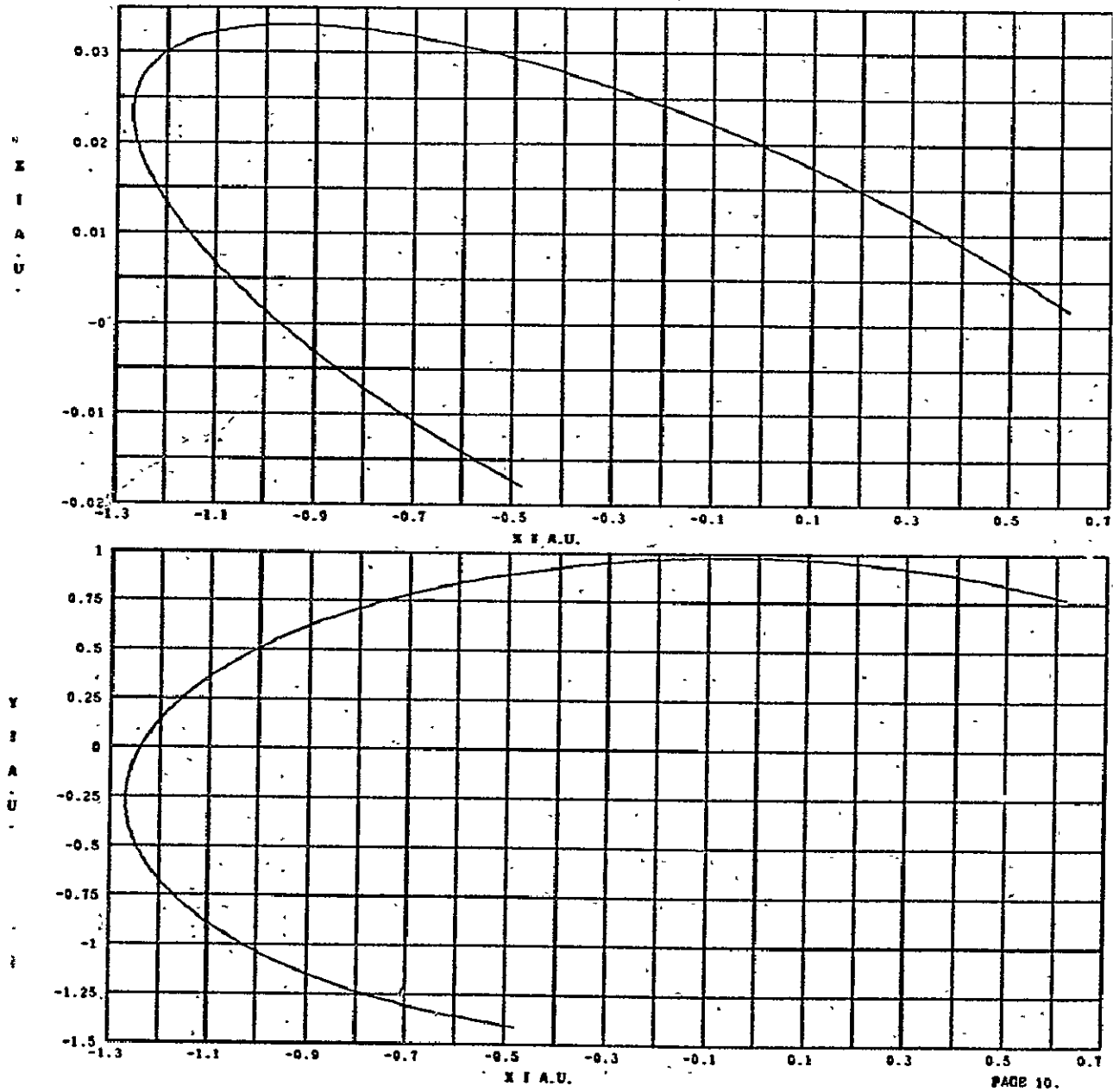
(c) Time histories of the true anomaly and mean anomaly.

Figure 9.- Continued.



(d) Time histories of the magnitudes of the position and velocity vectors.

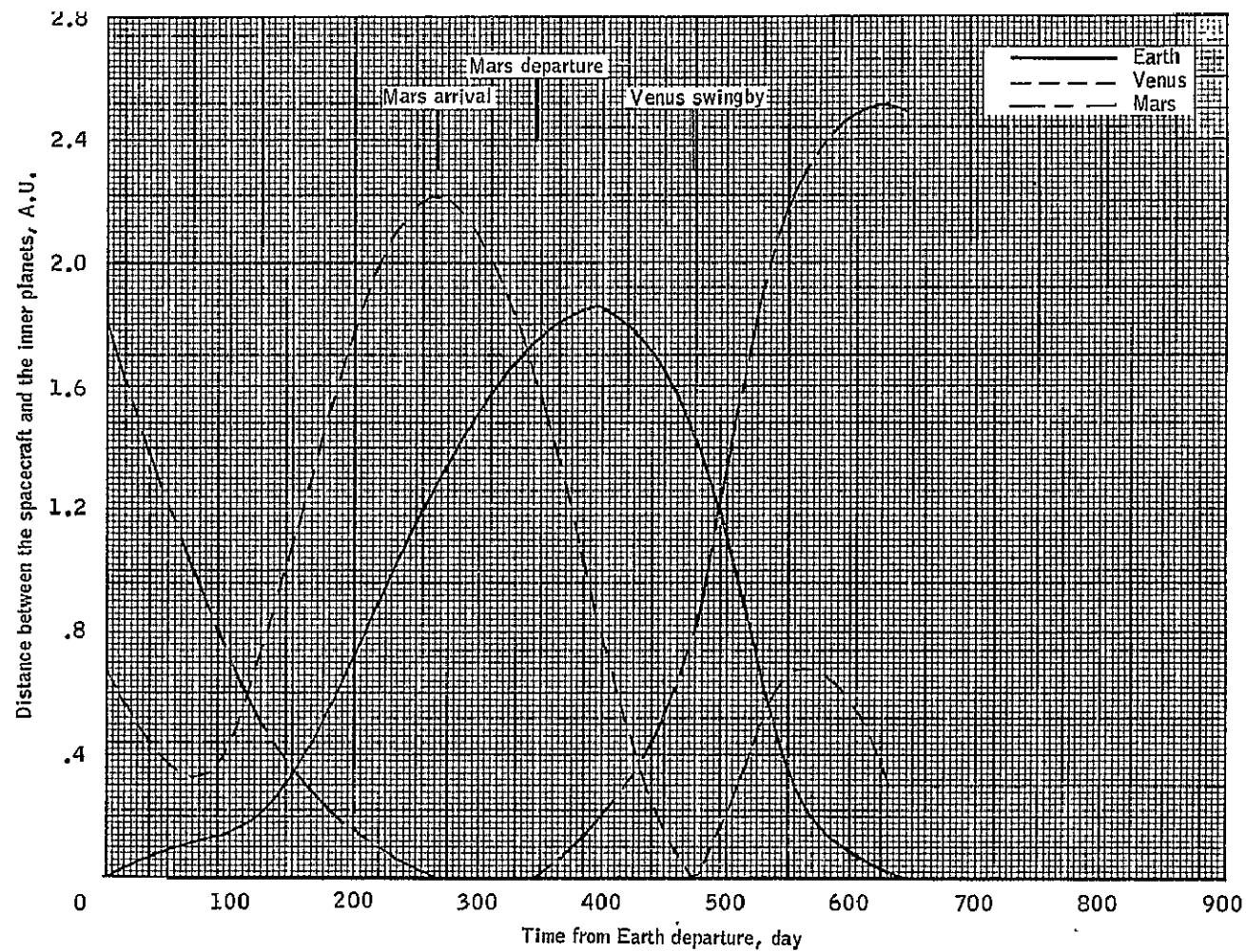
Figure 9.- Continued.



PAGE 10.

(e) Trajectory projections on the X-Y and X-Z planes.

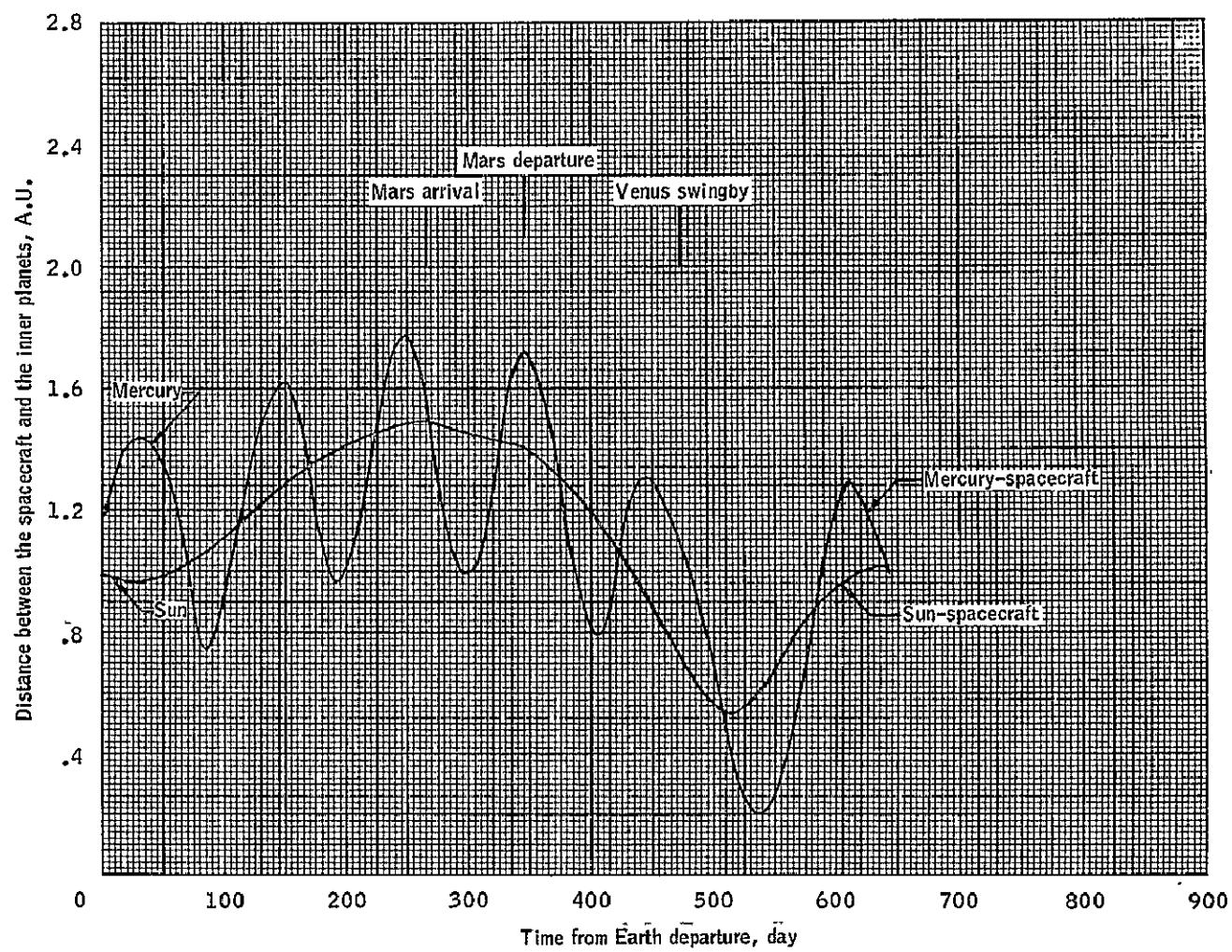
Figure 9.- Concluded.



(a) Earth, Mars, and Venus.

Figure 10.- Spacecraft relative distances to the inner planets and the Sun.

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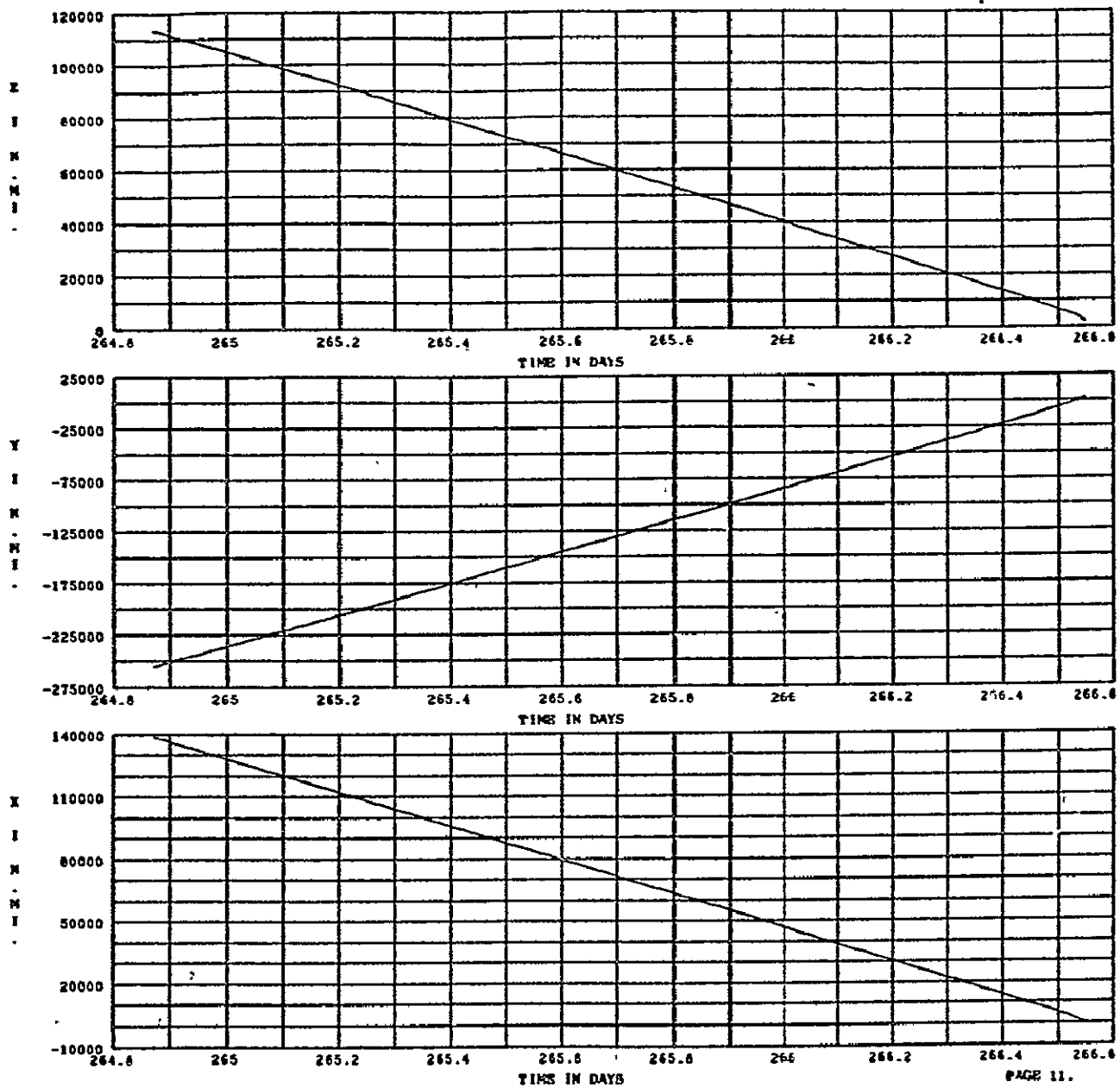
(b) Mercury and Sun.

Figure 10.- Concluded.

#### 6.4 Mars Orbit Insertion

The trajectory parameters for the portion of the mission from the Mars SOI to periapsis of the Mars arrival hyperbola are shown in figure 11. The coordinate system is the areocentric or Mars equatorial system. The transfer angle is  $115^\circ$ , and the flight time is 40.3 hours. The velocity at the Mars SOI is 12 859 fps, and the velocity at periapsis is 20 203 fps. Mars orbit insertion is simulated by a single impulsive thrusting maneuver of 6221 fps excluding propulsion losses. The resulting orbit around Mars is 200 by 6322 n. mi. with an inclination of  $75^\circ$ .

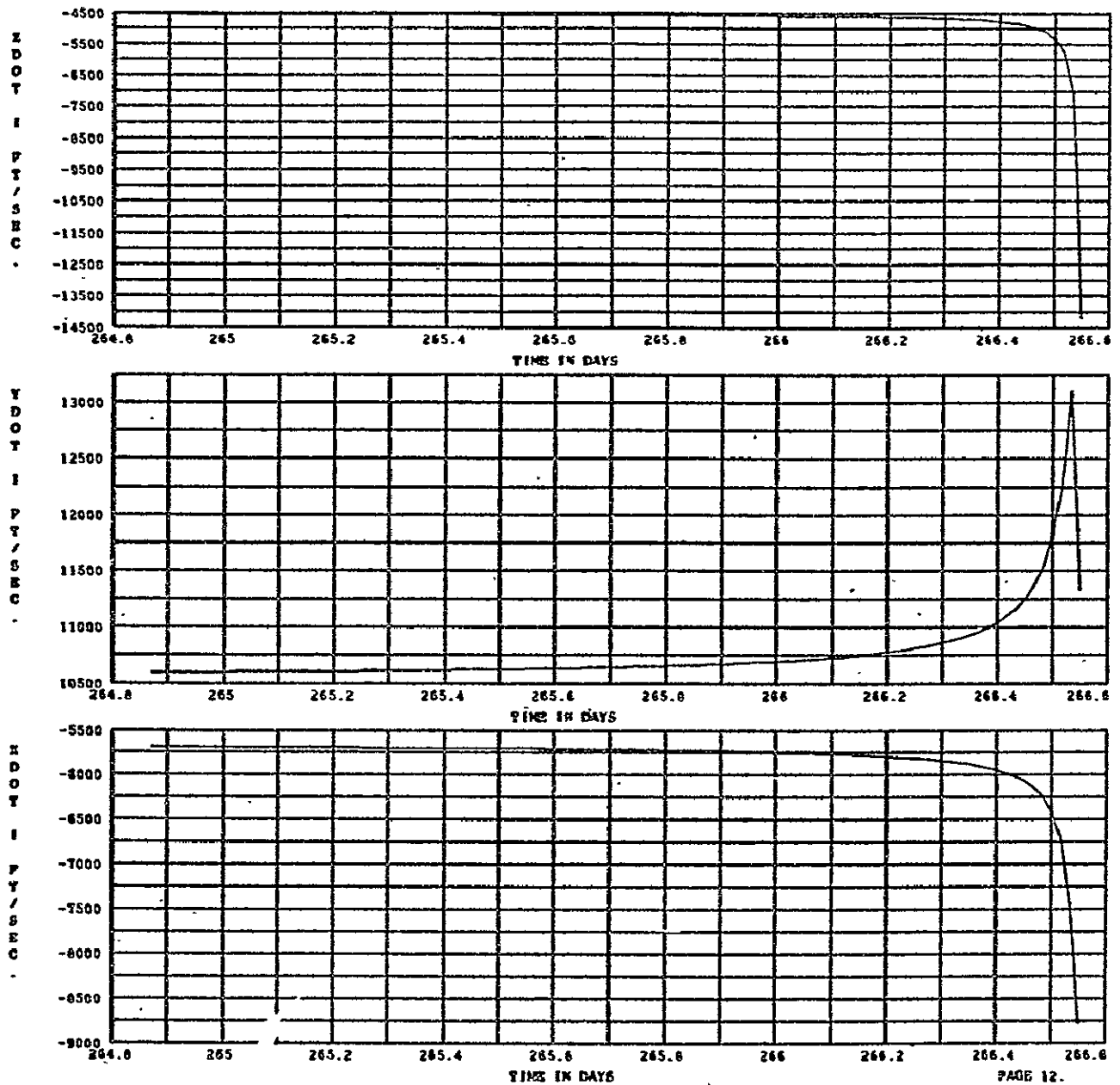
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(a) Time histories of the Cartesian components of the position vector.

Figure 11.- Mars arrival trajectory parameters (areocentric or Mars equatorial coordinate system) sphere of influence to periapsis.

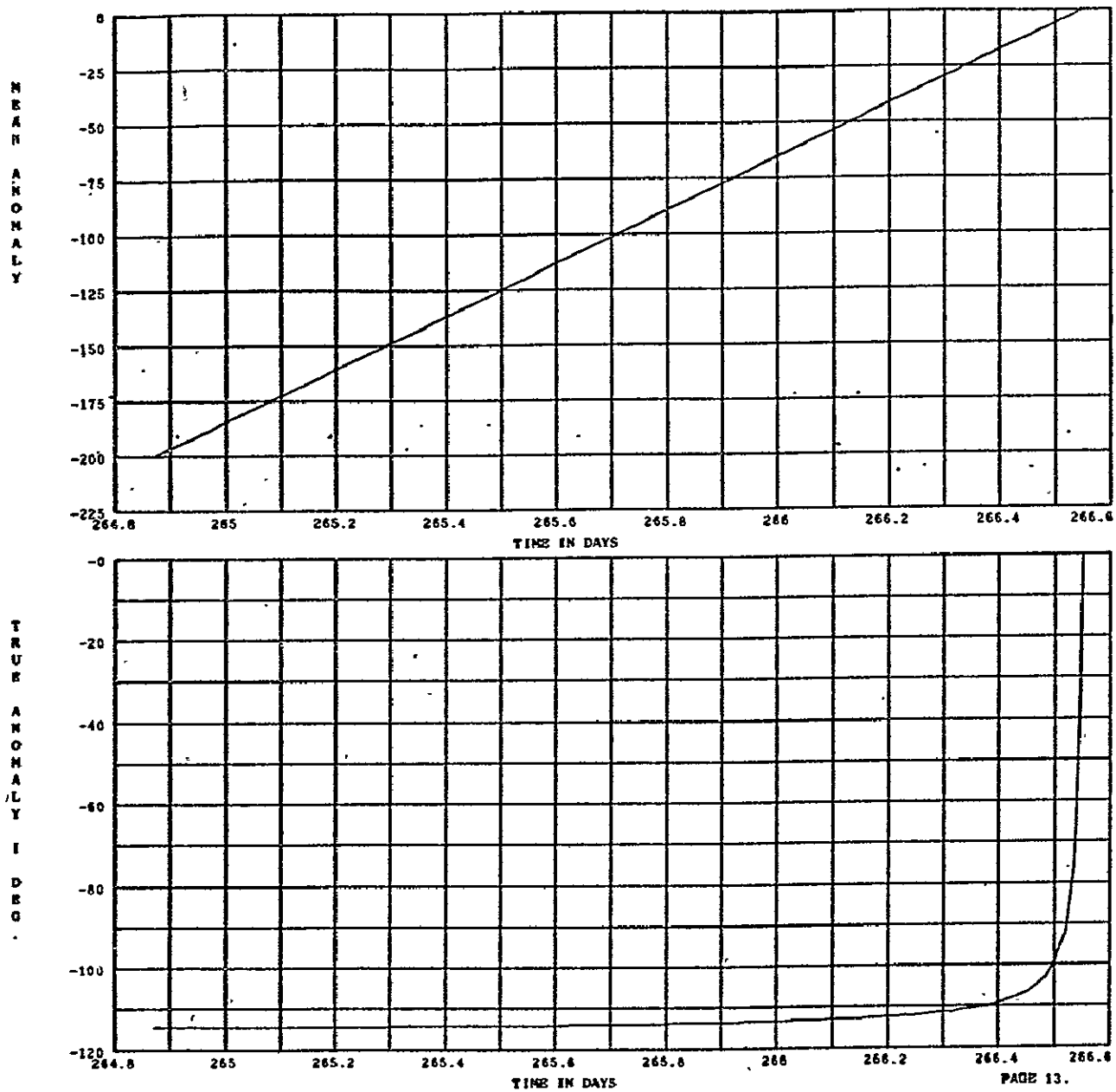




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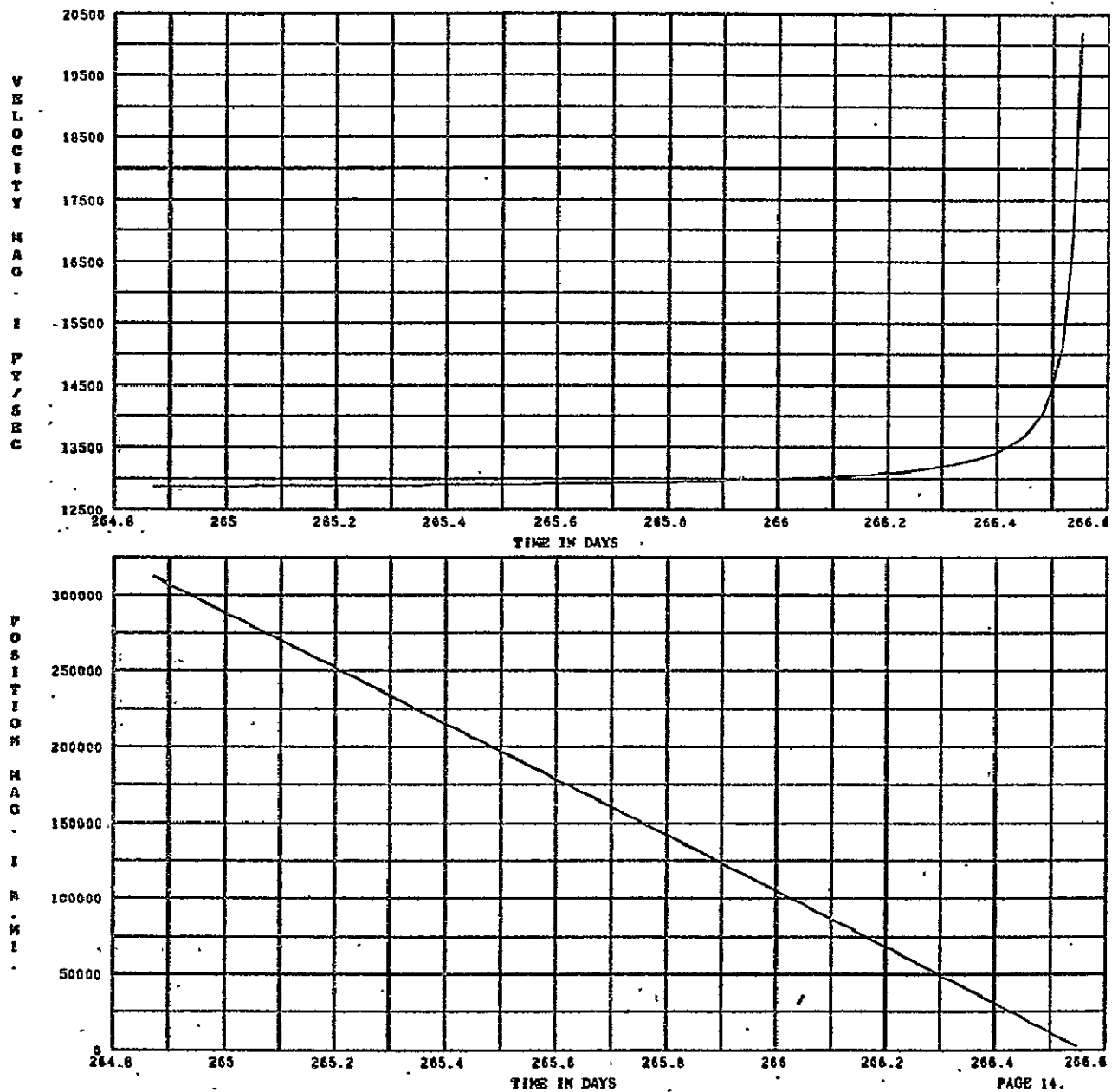
(b) Time histories of the Cartesian components of the velocity vector.

Figure 11.- Continued.



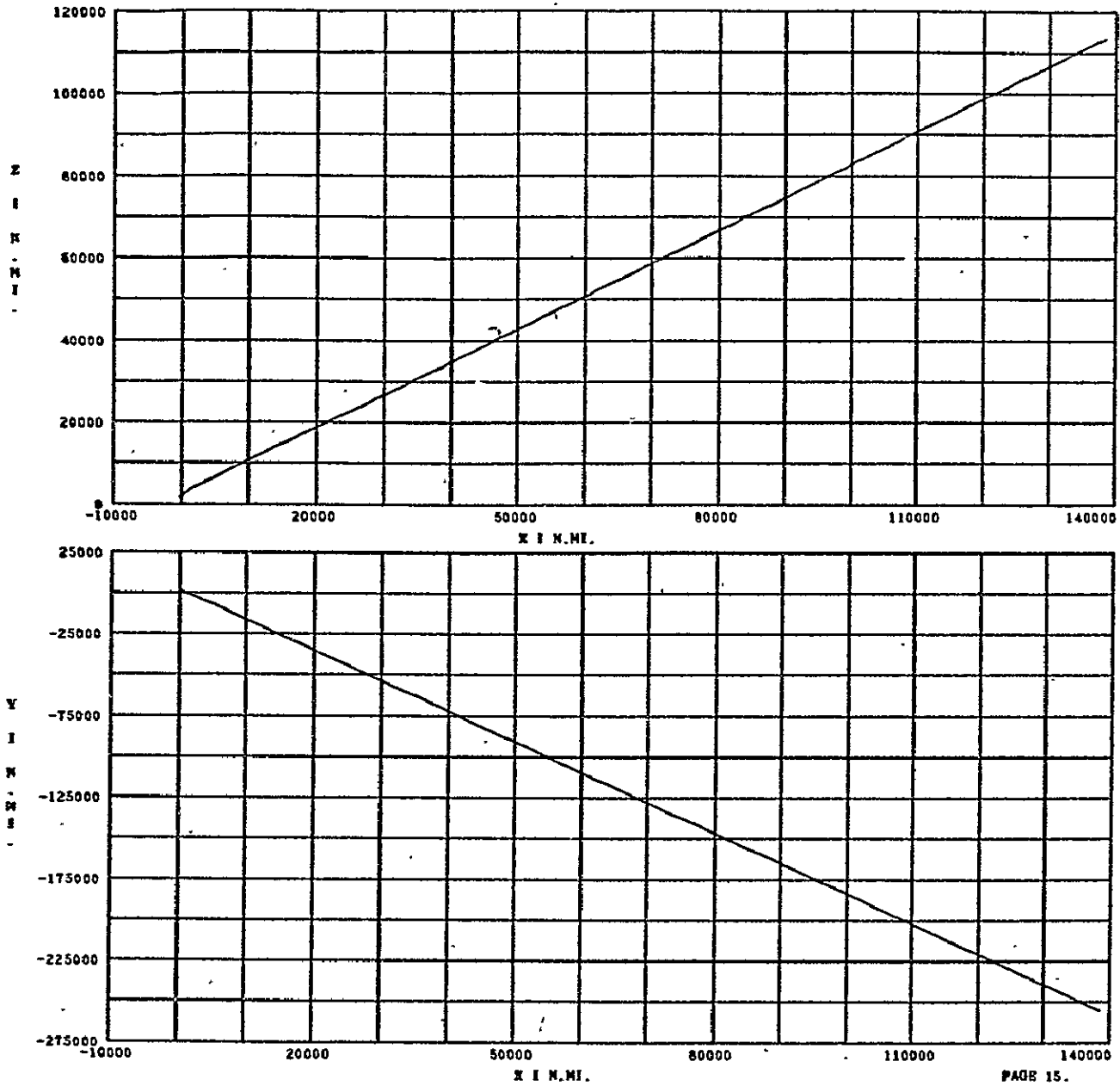
(c) Time histories of the true anomaly and mean anomaly.

Figure 11.- Continued.



(d) Time histories of the magnitudes of the position and velocity vectors.

Figure 11 - Continued.



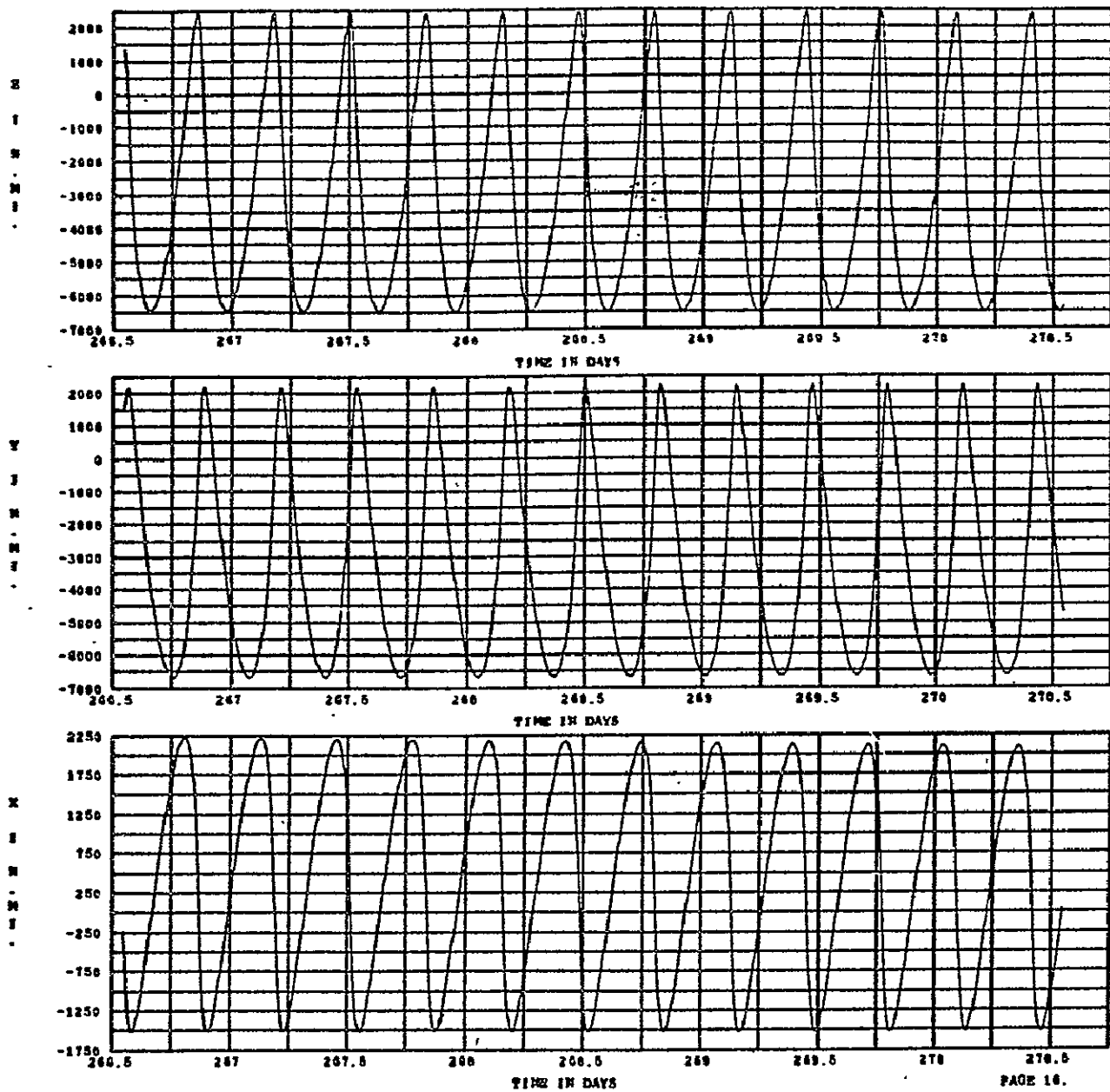
(e) Trajectory projections on the X-Y and X-Z planes.

Figure 11.- Concluded.

## 6.5 Mars Parking Orbit

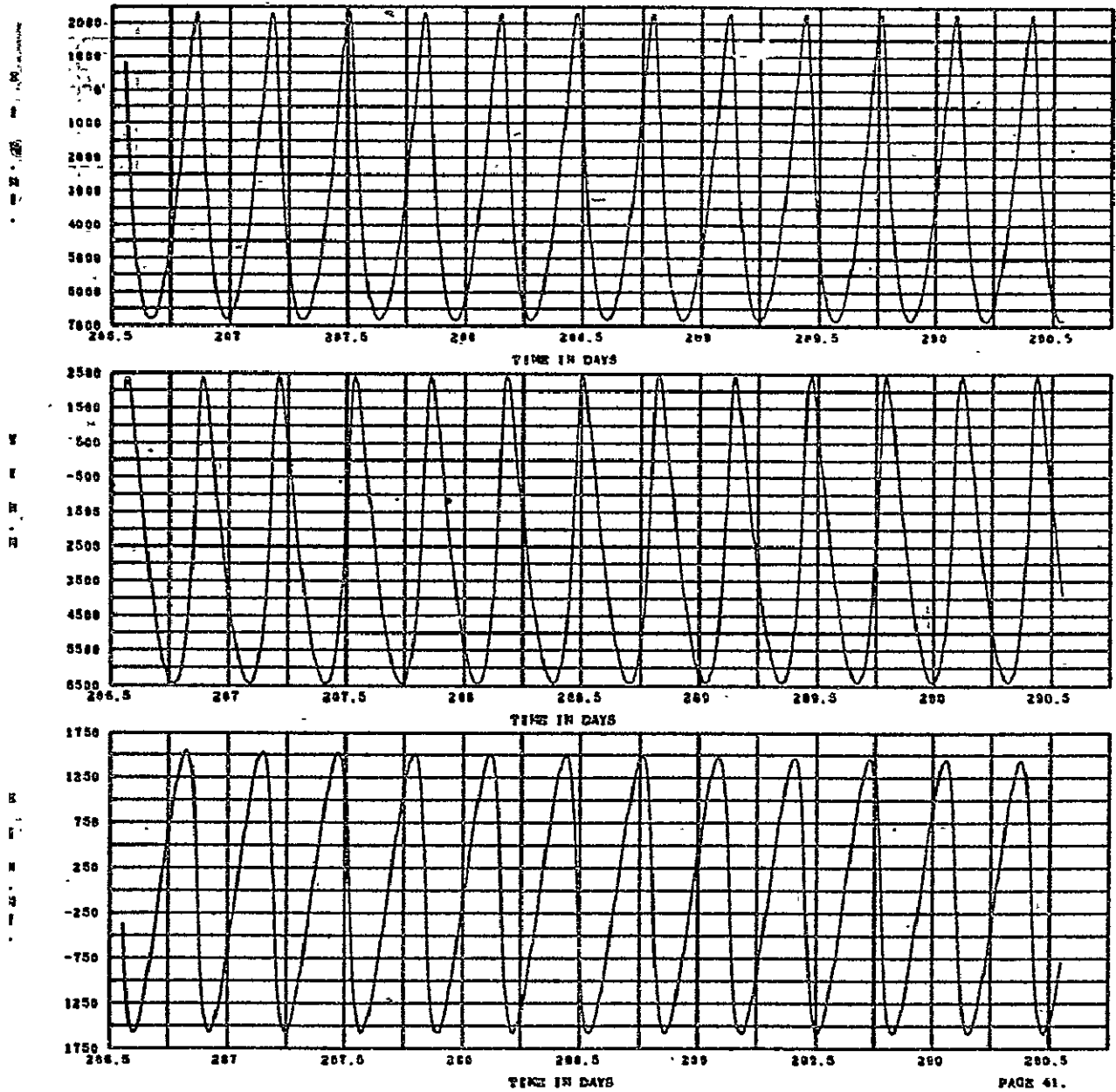
The parking orbit around Mars is 200 by 6322 n. mi. with an inclination of  $75^\circ$ . The orbital period is 7.73 hours. The initial longitude of the ascending node and argument of periapsis are  $292.46^\circ$  and  $136.81^\circ$ , respectively. This orbit was selected from several possible orbits, all of which exhibit the characteristic of being aligned with the hyperbolic approach and departure periapsis positions. The oblate gravitational field of Mars causes the initial periapsis position to be perturbed to the position of the required departure periapsis following an 80-day stay at Mars. References 8 and 9 present detailed analyses of this parking orbit alinement technique. The rather high orbit inclination ( $75^\circ$ ) was selected because of the desire to locate the landing site near the edge of the North polar cap. Some interest has been expressed in this area because the results of the Mariner VI and VII flights have become available.

A time history of the parking orbit trajectory parameters accounting for first and second order secular perturbations based on epoch values for selected orbits is given in figure 12. A complete time history from arrival to departure would involve about five times the data actually presented. This amount of detail is not necessary at this time; therefore, only those periods involving significant activity (e.g.; MOI, MEM operations, and TEI) are included. The coordinate system is the Mars equatorial system. The Mars groundtracks of selected revolutions (1 through 4, 63 through 66, 157 through 160, and 246 through 248) are given in figure 13. These groundtracks correspond to the time of arrival, Mars lander descent, Mars lander ascent, and Mars departure, respectively. The spacecraft is in sunlight during the entire 80-day stay except for a few minutes during the first and second revolutions. The Mars orbital elements were selected on the basis of secular perturbation; thus, the semimajor axis, eccentricity, and inclination are assumed constant. The first order short and long period perturbations have been examined, and these effects are included in the time histories shown in figure 14. Variations in inclination are less than  $0.025^\circ$ . The eccentricity varies less than 0.0043, and variations in the semimajor axis are less than 65 n. mi. The current knowledge of the Mars gravitational field is insufficient for precise orbit prediction, and the periodic perturbations can be ignored at least for the present. The techniques used for the Mars orbit propagation data are discussed in references 10 and 11.



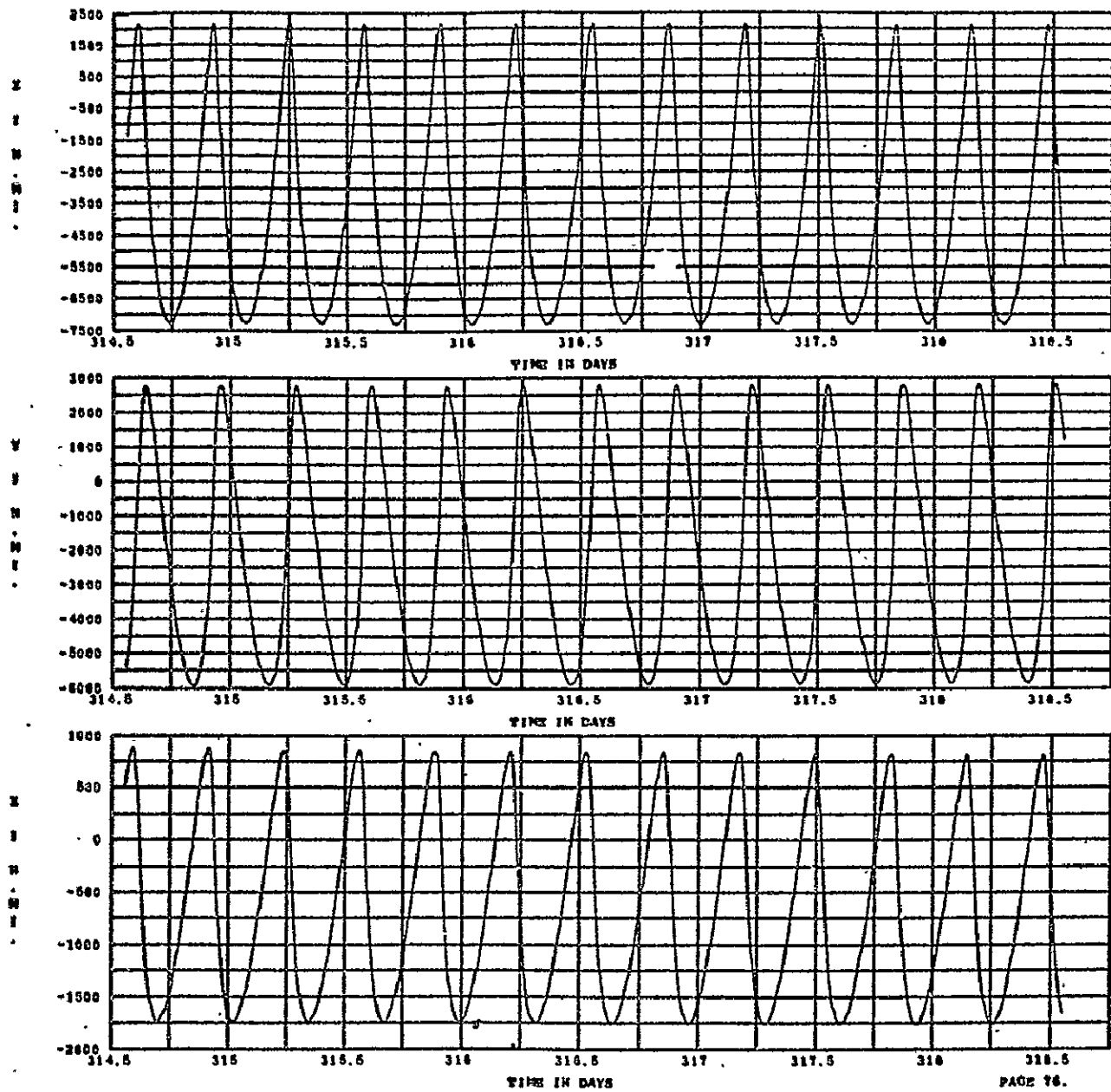
(a) Time histories of the Cartesian components of the position vector.

Figure 12.- Mars orbit parameters accounting for first and second order secular perturbations based on epoch values (areocentric or Mars equatorial coordinate system), periapsis at arrival to periapsis at departure.



(a) Time histories of the Cartesian components of the position vector-continued.

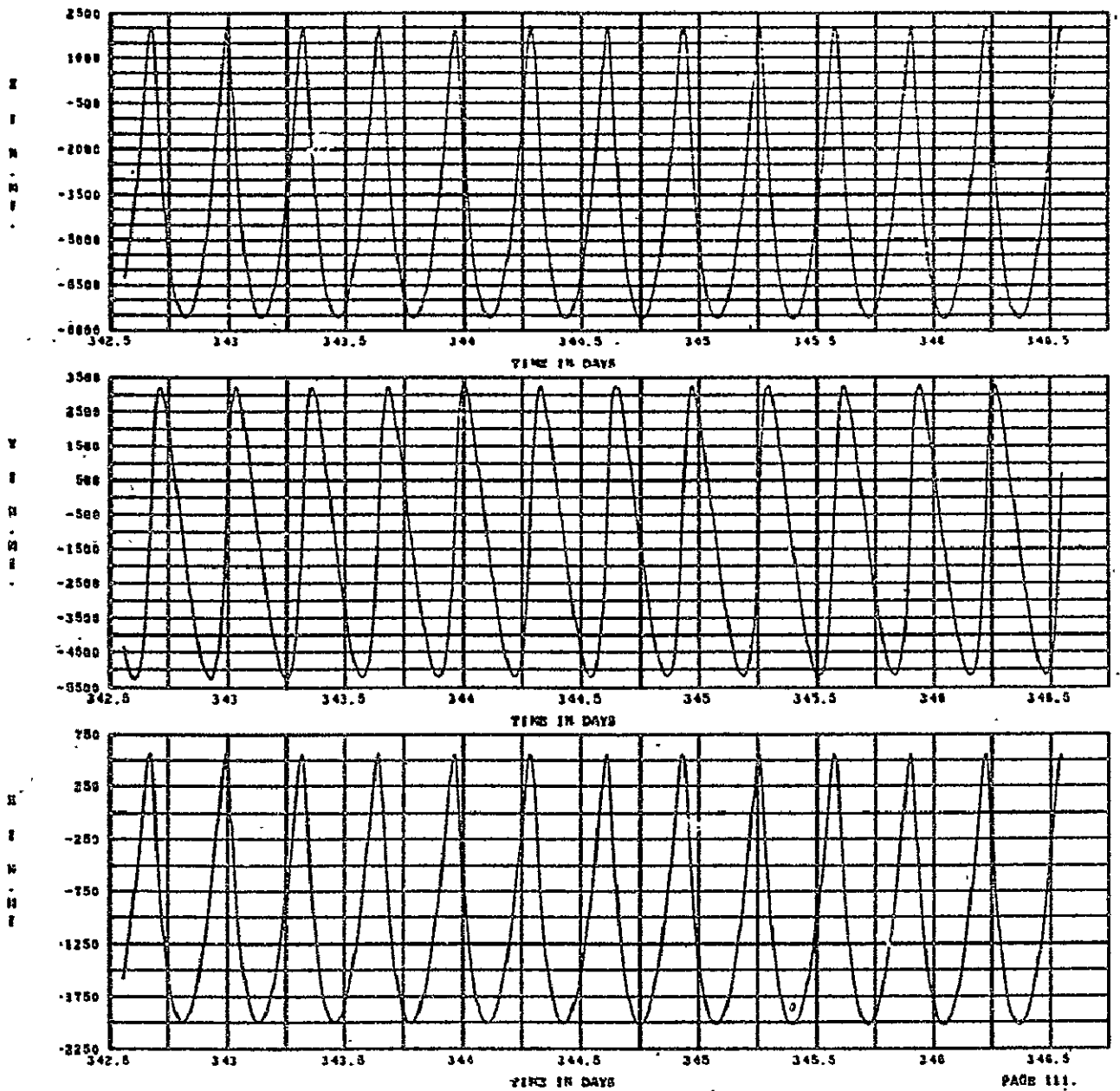
Figure 12.-Continued.



(a) Time histories of the Cartesian components of the velocity vector-continued.

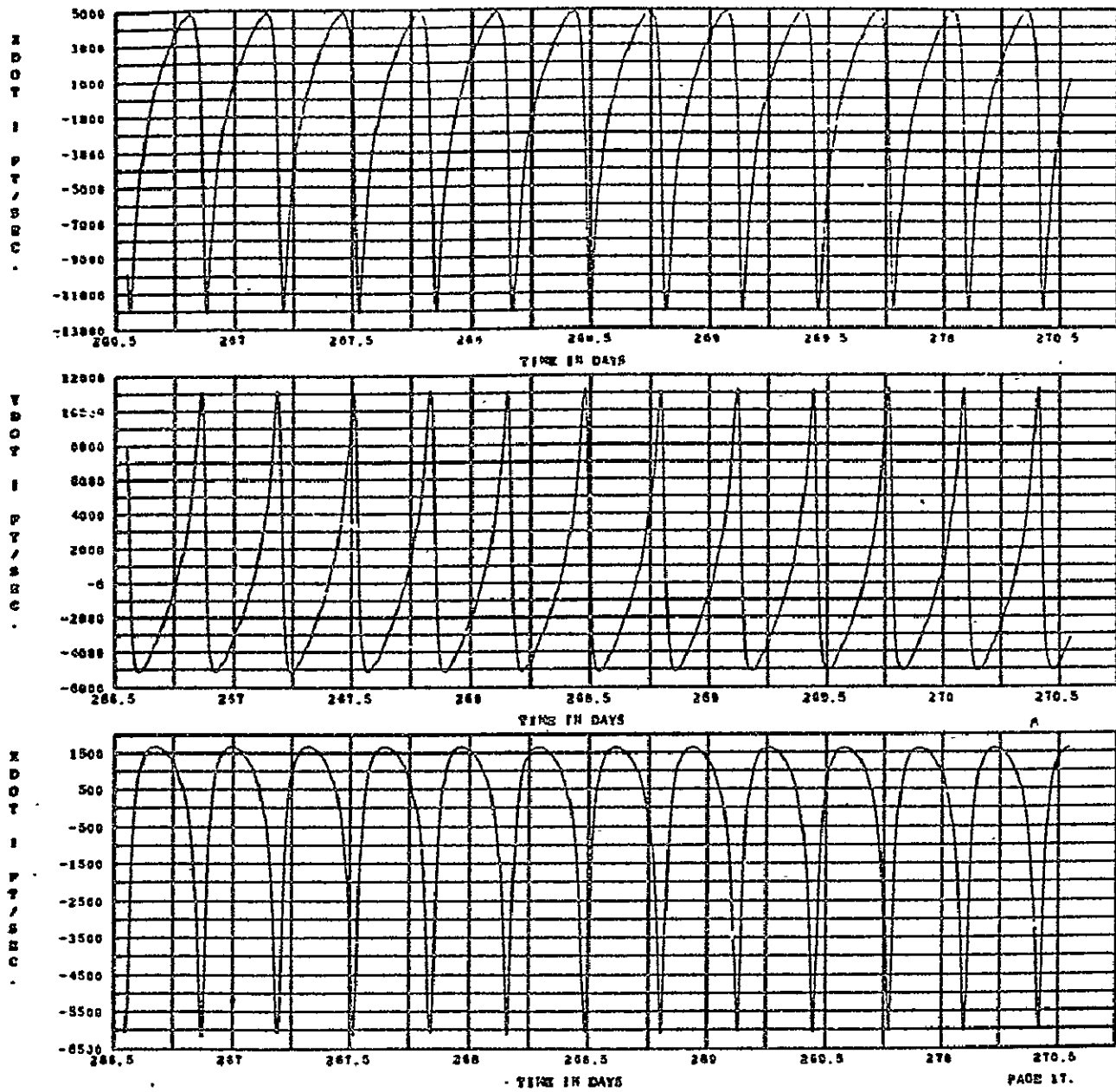
Figure 12 - Continued





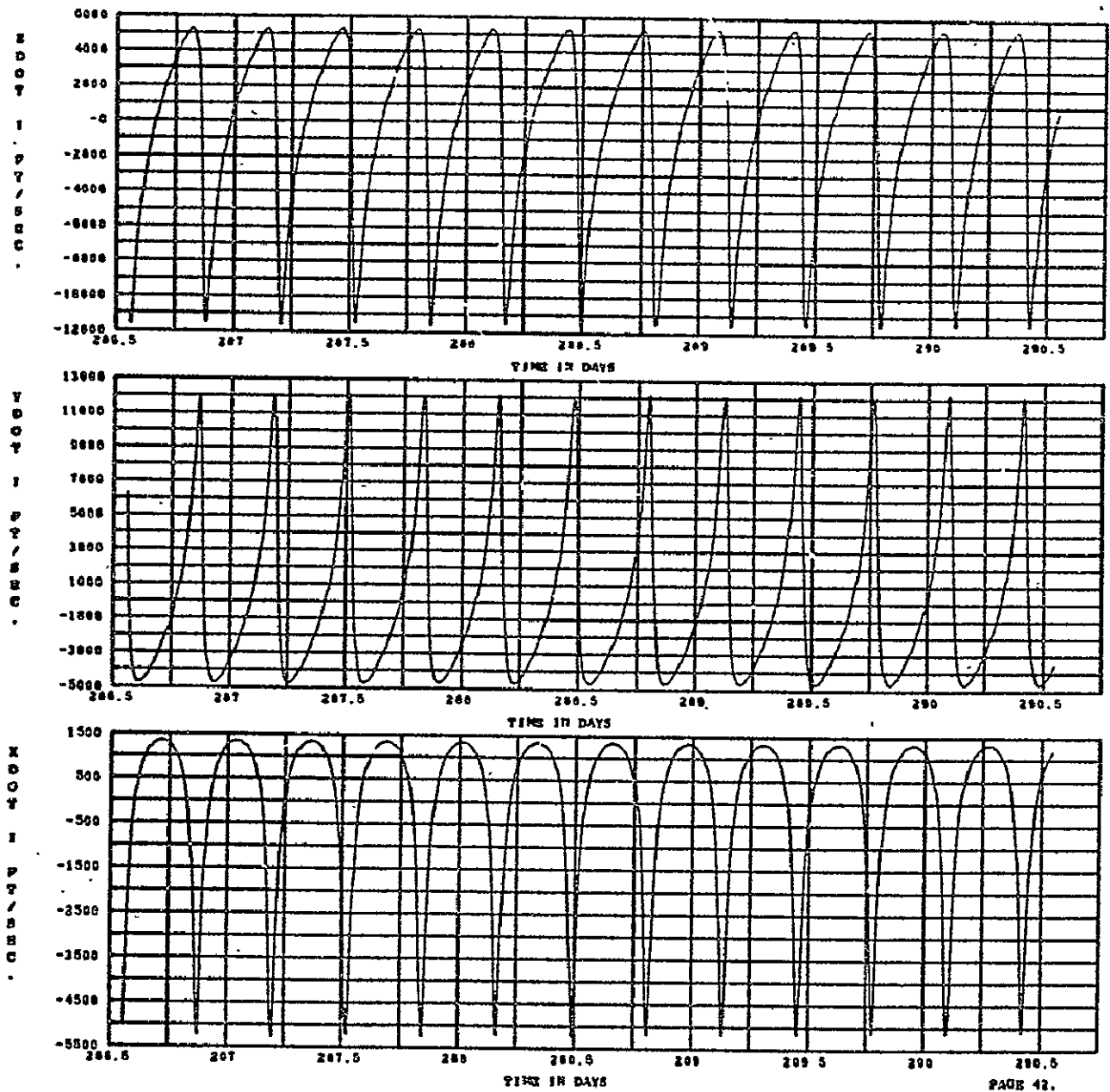
(a) Time histories of the Cartesian components of the position vector—concluded.

Figure 12.- Continued.



(b) Time histories of the Cartesian components of the velocity vector.

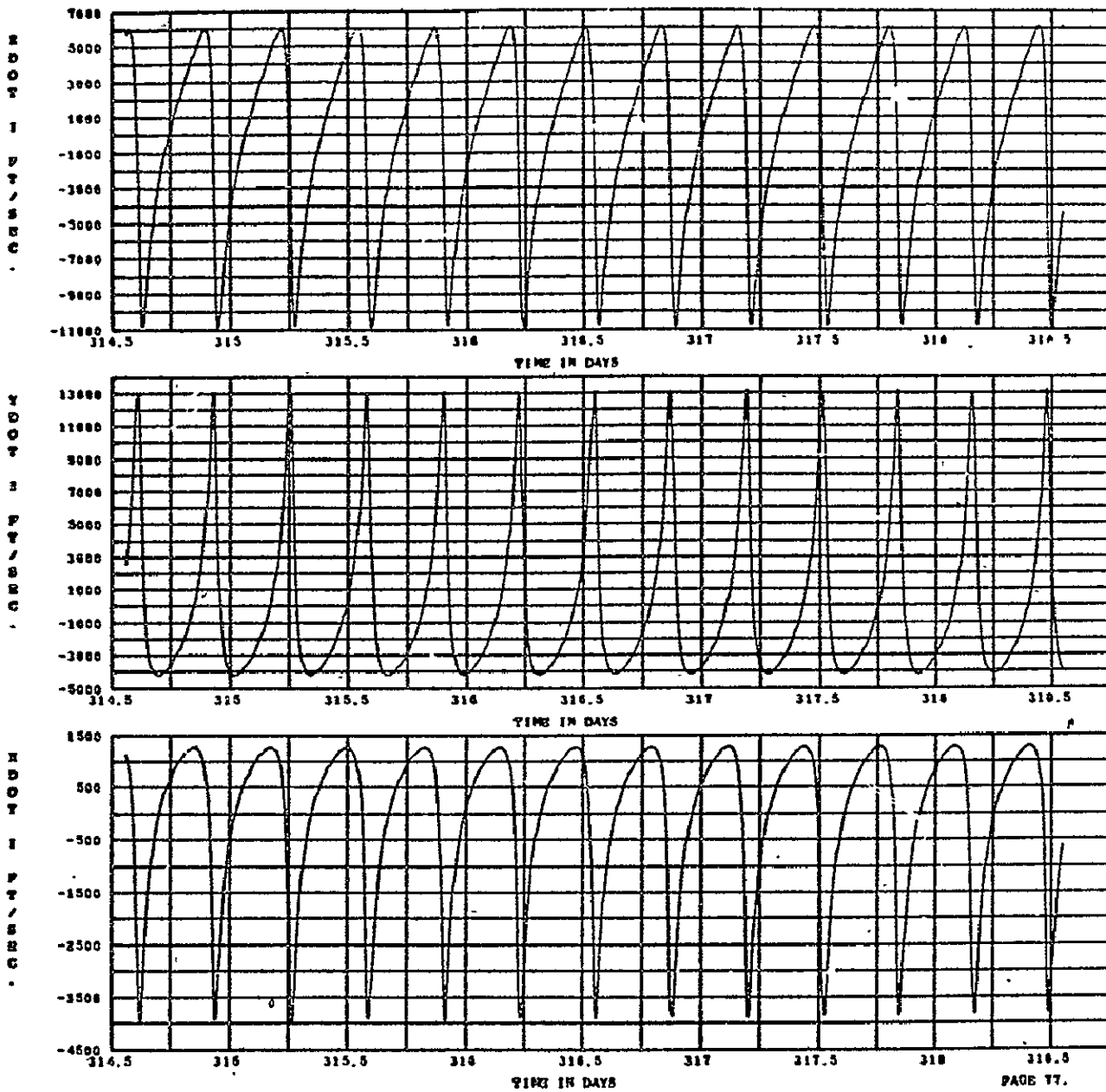
Figure 12.- Continued.



(b) Time histories of the Cartesian components of the velocity vector-continued.

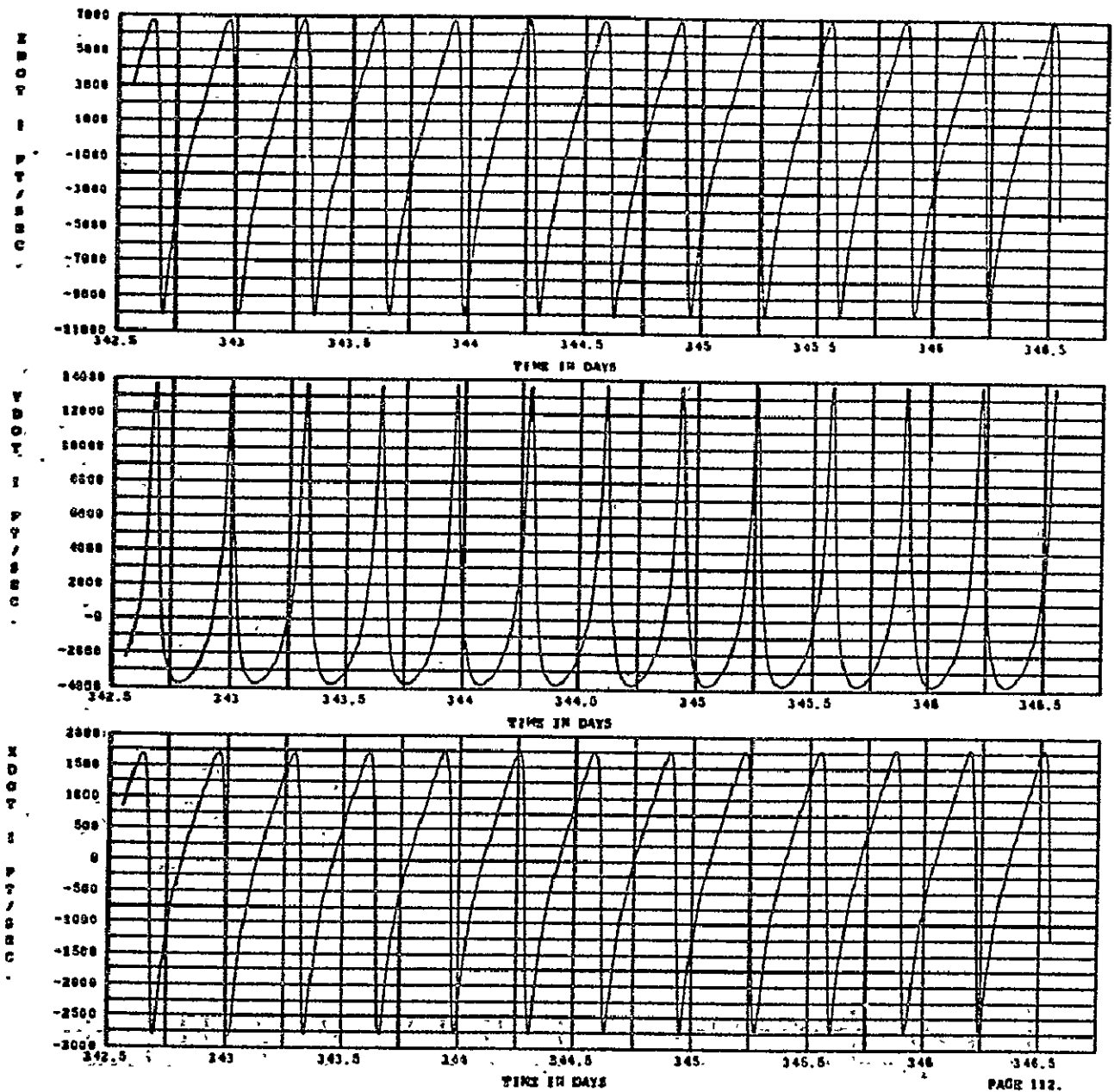
Figure 12.- Continued.

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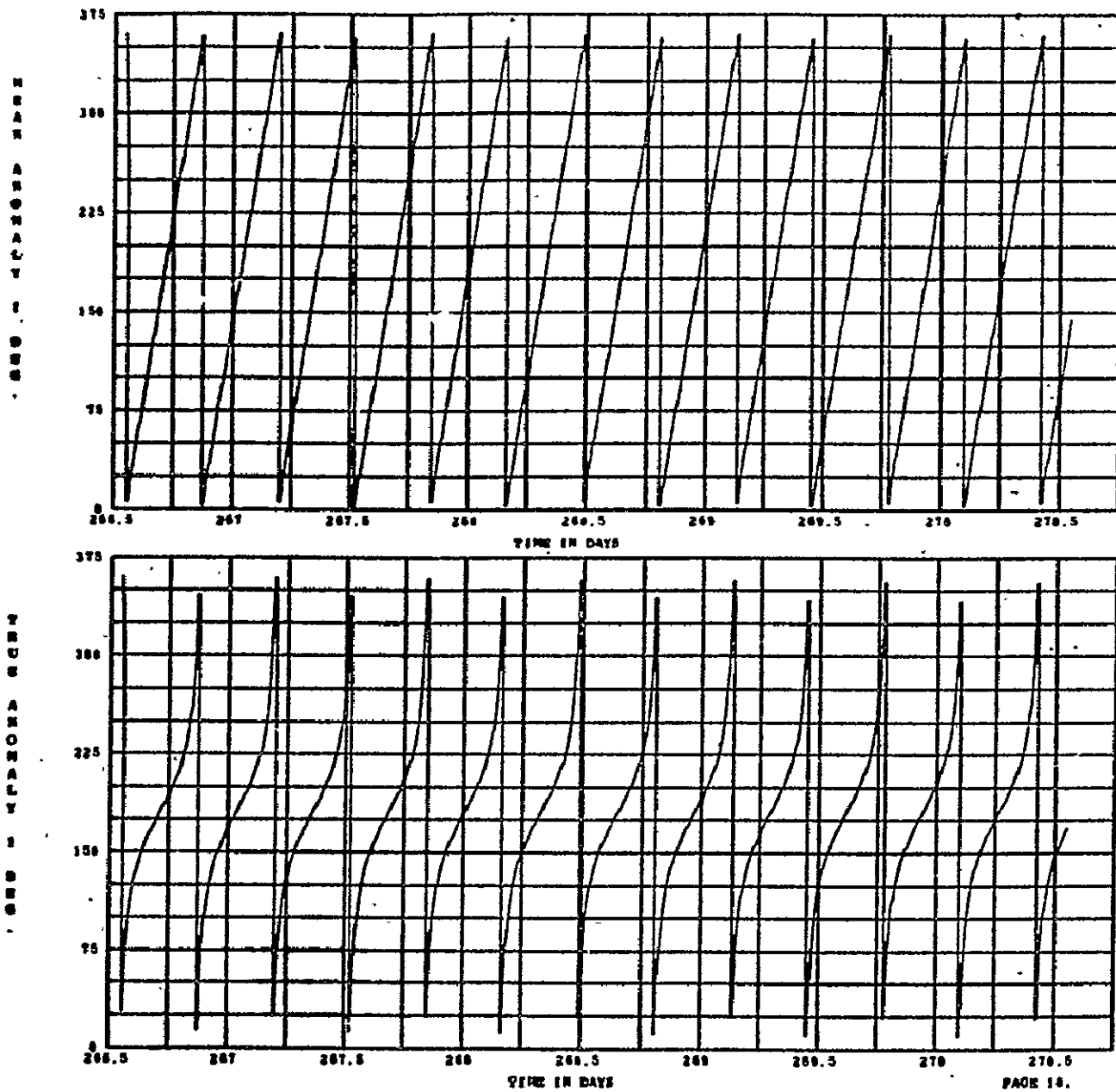
(b) Time histories of the Cartesian components of the velocity vector—continued.

Figure 12.- Continued.



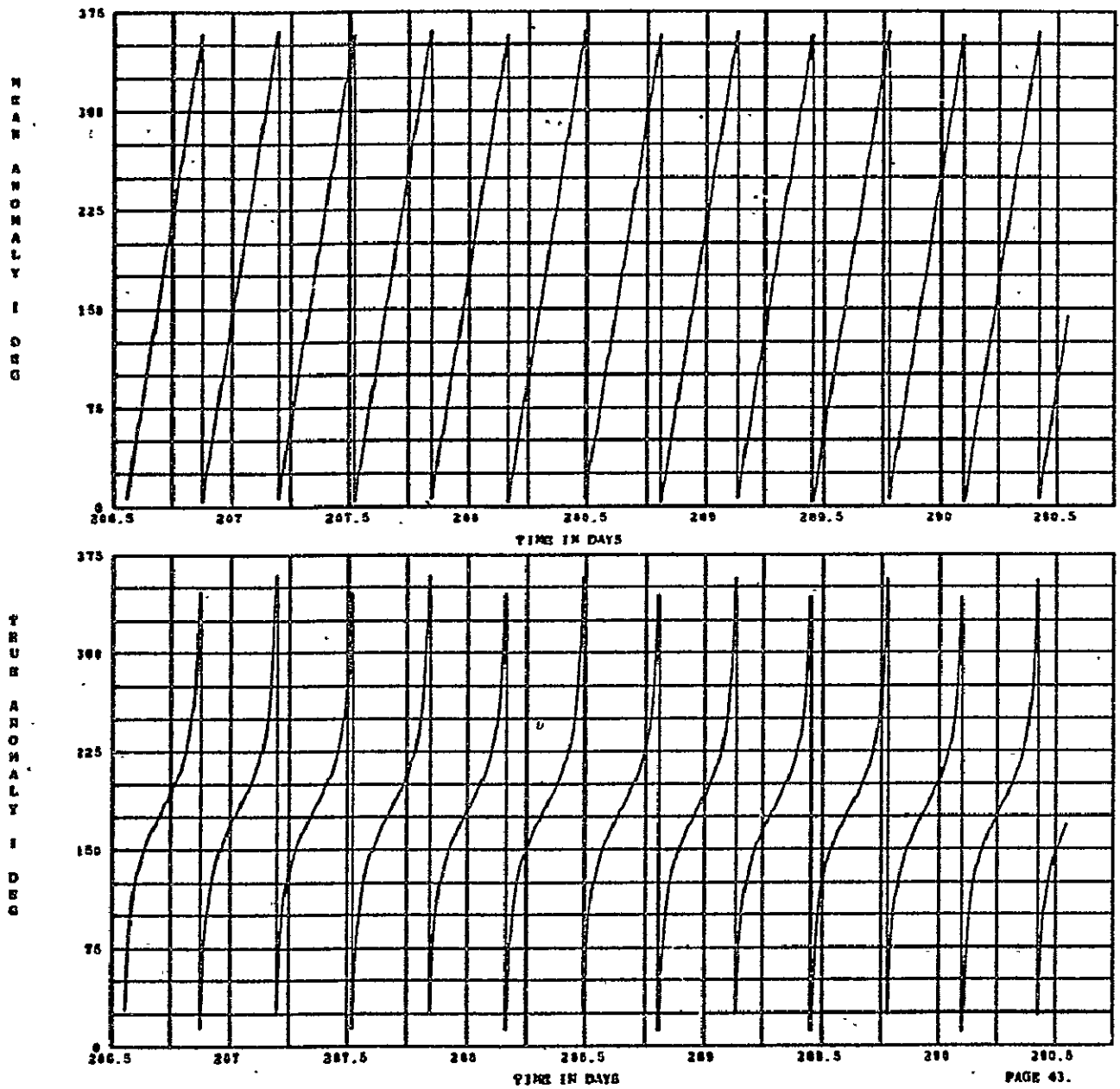
(b) Time histories of the Cartesian components of the velocity vector-  
concluded.

Figure 12.- Continued.



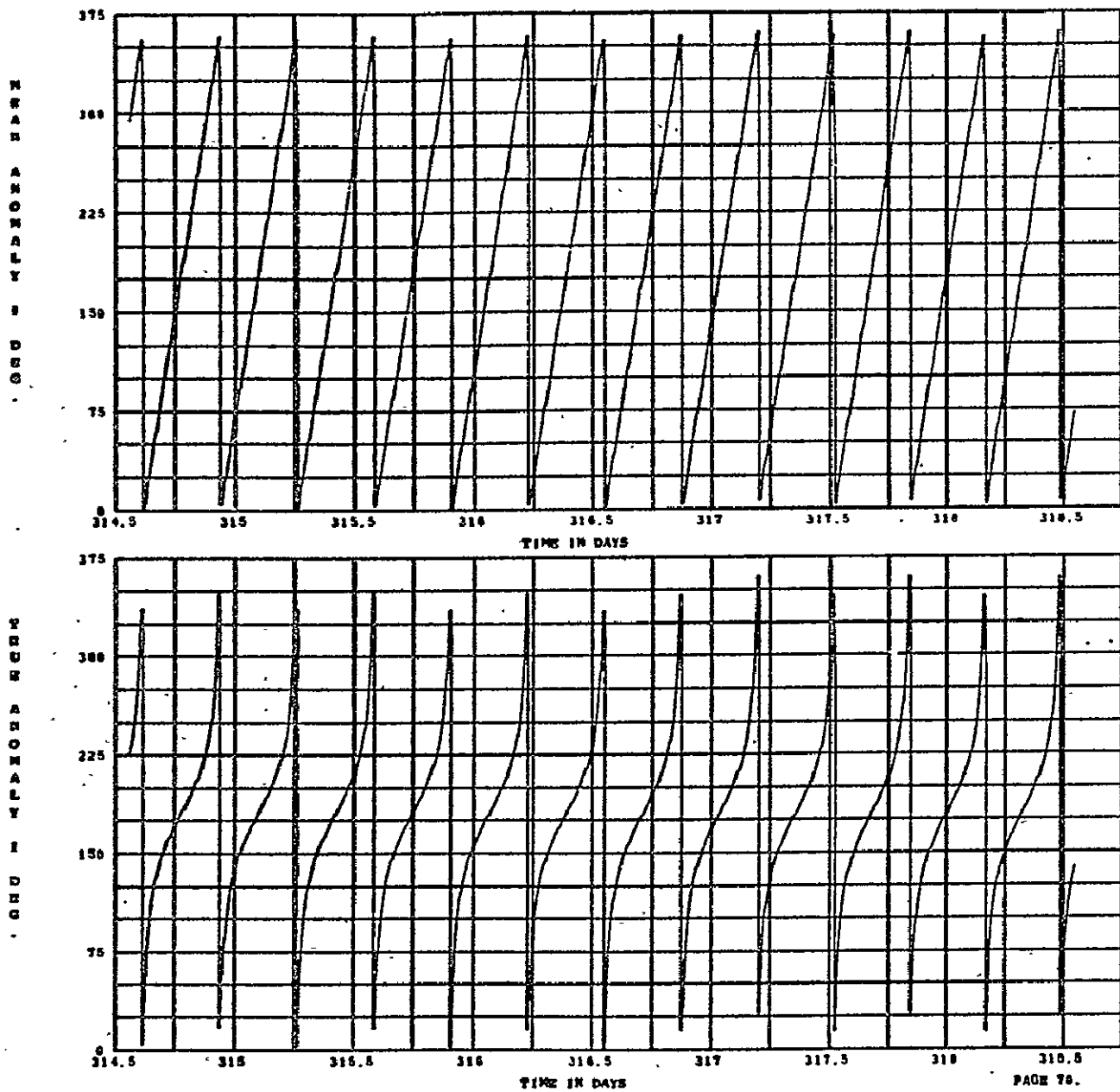
(c) Time histories of the true anomaly and mean anomaly.

Figure 12.- Continued.



(c) Time histories of the true anomaly and mean anomaly - continued.

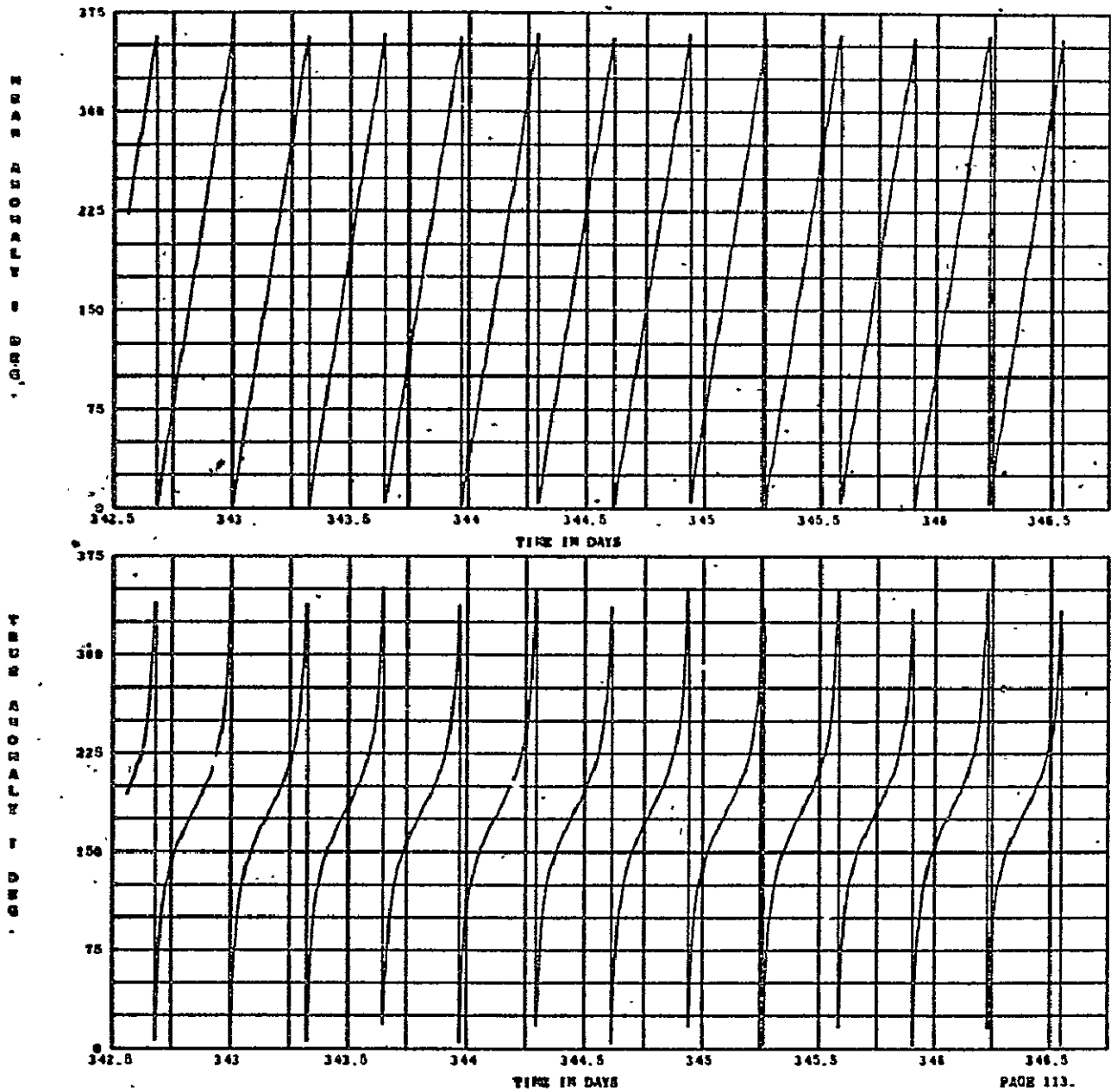
Figure 12.- Continued.



c) Time histories of the true anomaly and mean anomaly - continued.

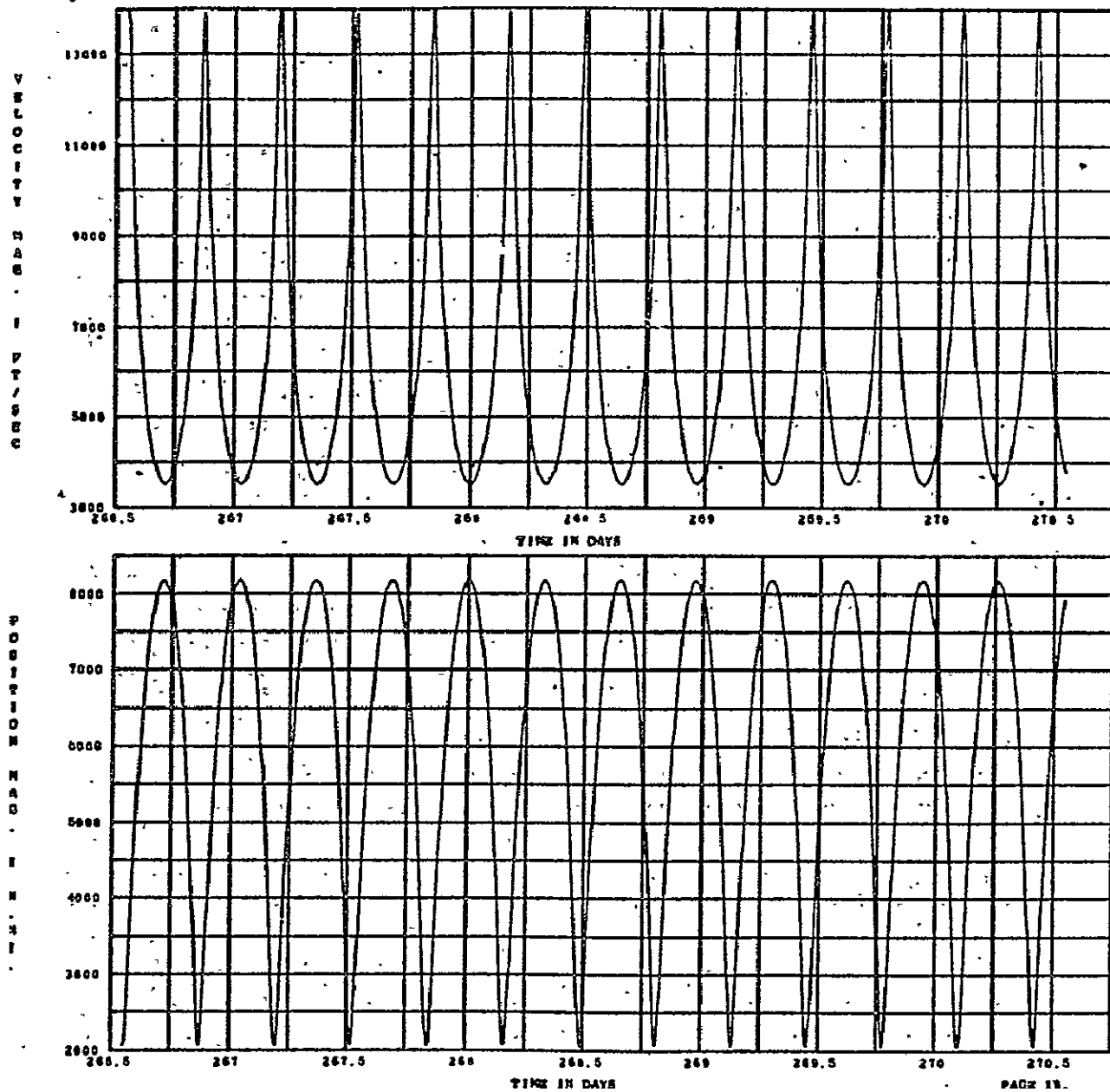
Figure 12.- Continued.





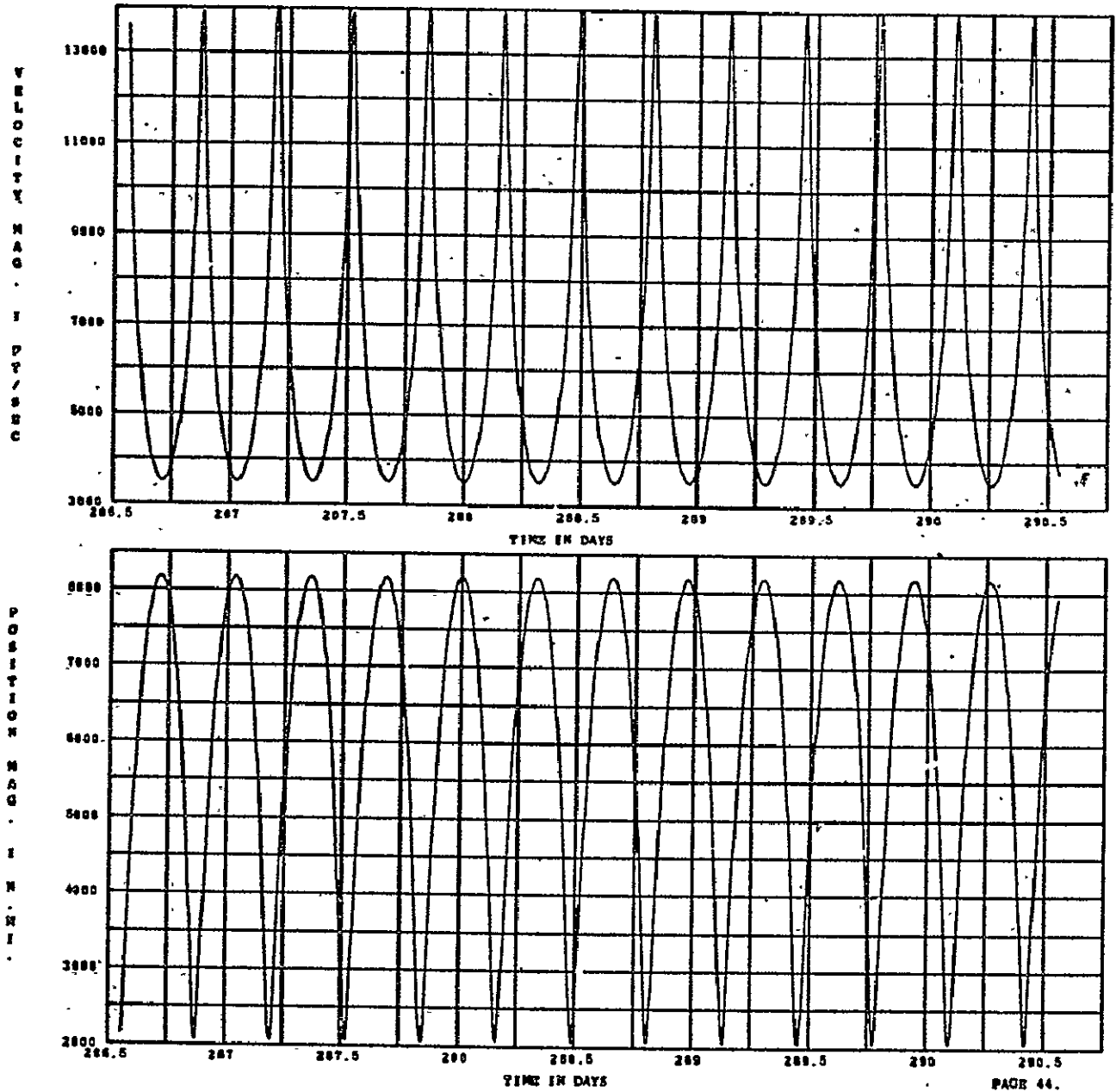
(c) Time histories of the true anomaly and mean anomaly - concluded.

Figure 12.- Continued.



(d) Time histories of the magnitudes of the position and velocity vectors.

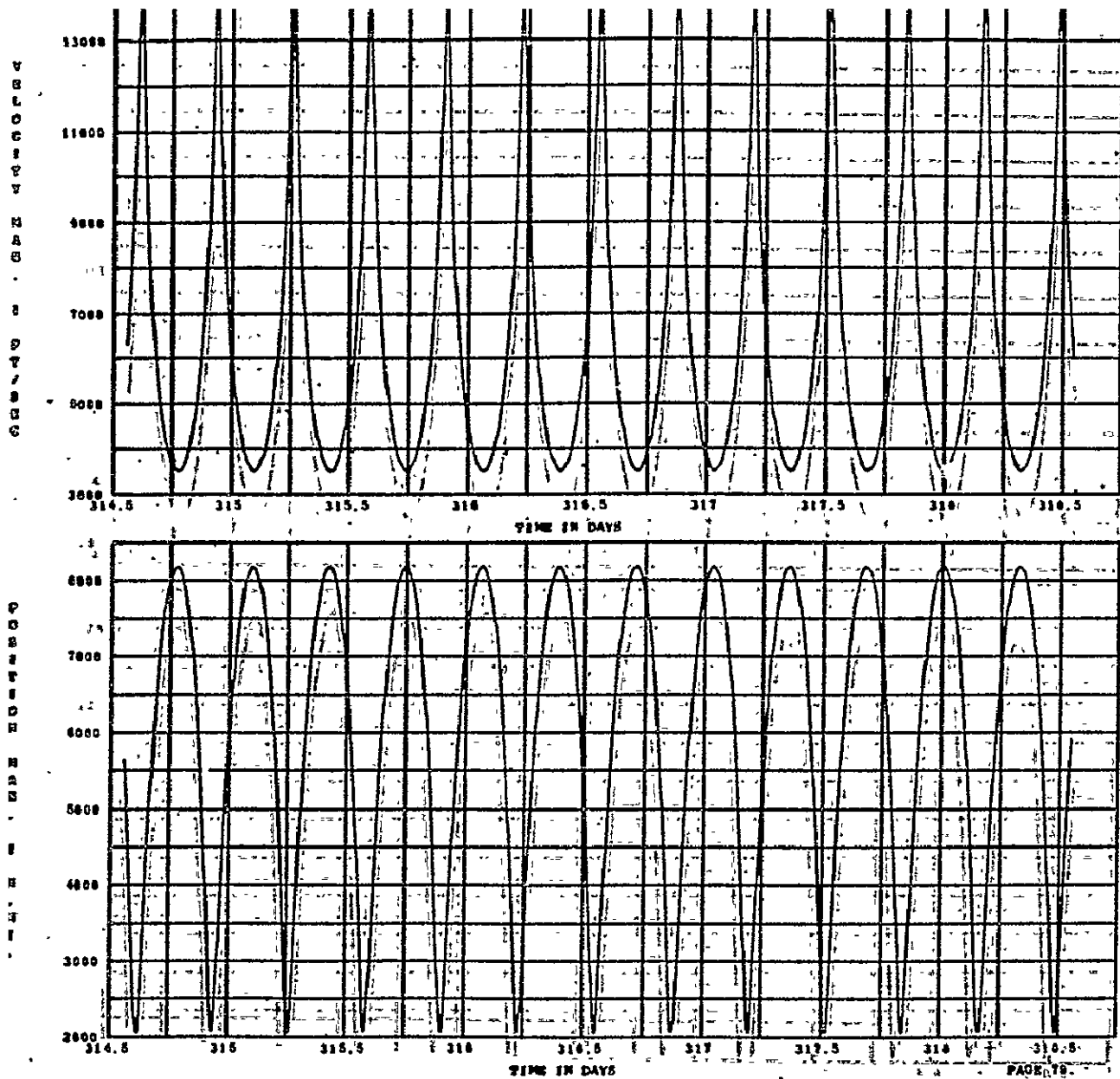
Figure 12.- Continued.



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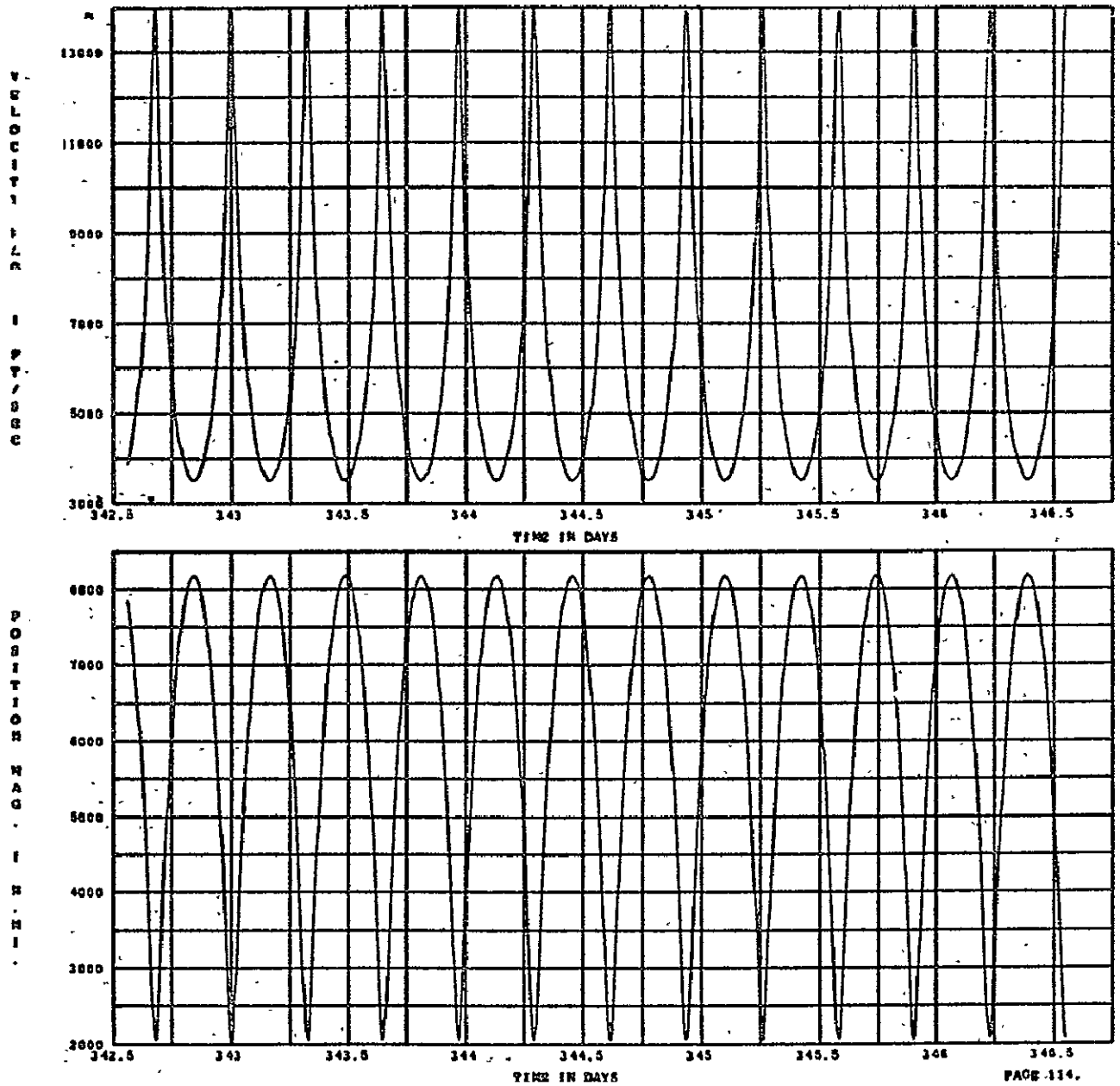
(d) Time histories of the magnitudes of the position and velocity vectors - continued.

Figure 12.- Continued.



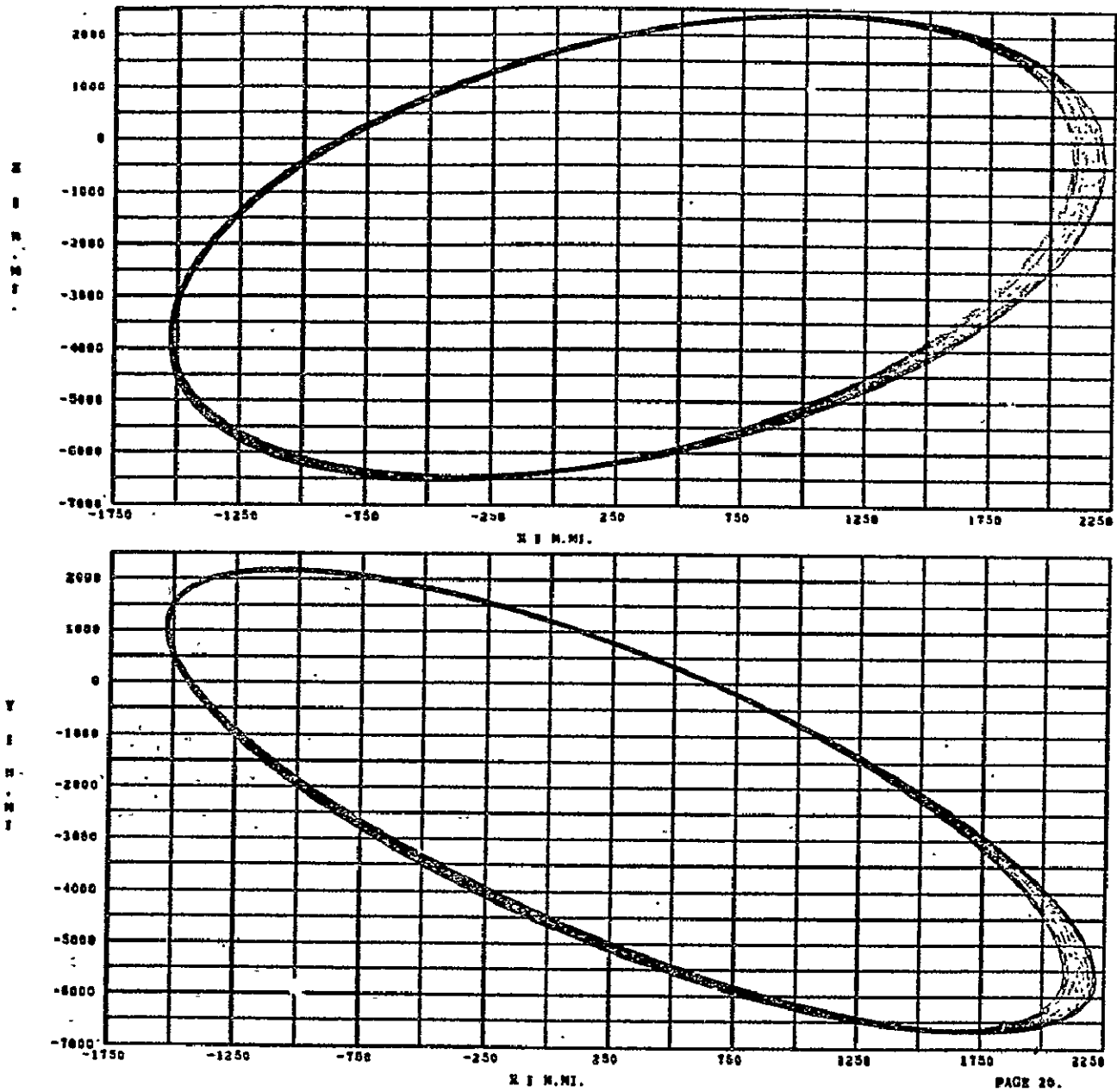
(d) Time histories of the magnitudes of the position and velocity vectors continued.

Figure 12.- Continued.



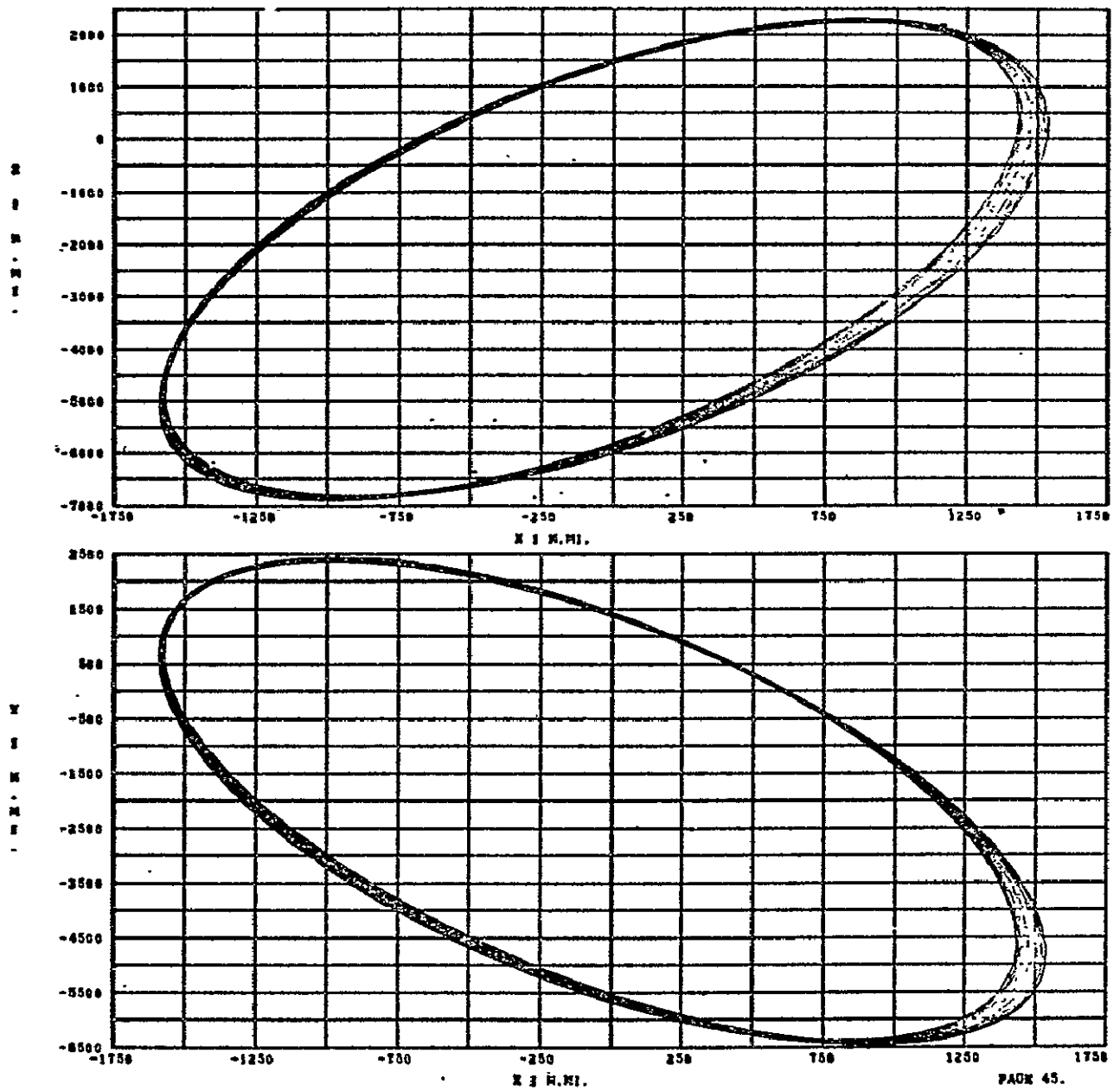
(d) Time histories of the magnitudes of the position and velocity vectors concluded.

Figure 12.- Continued.



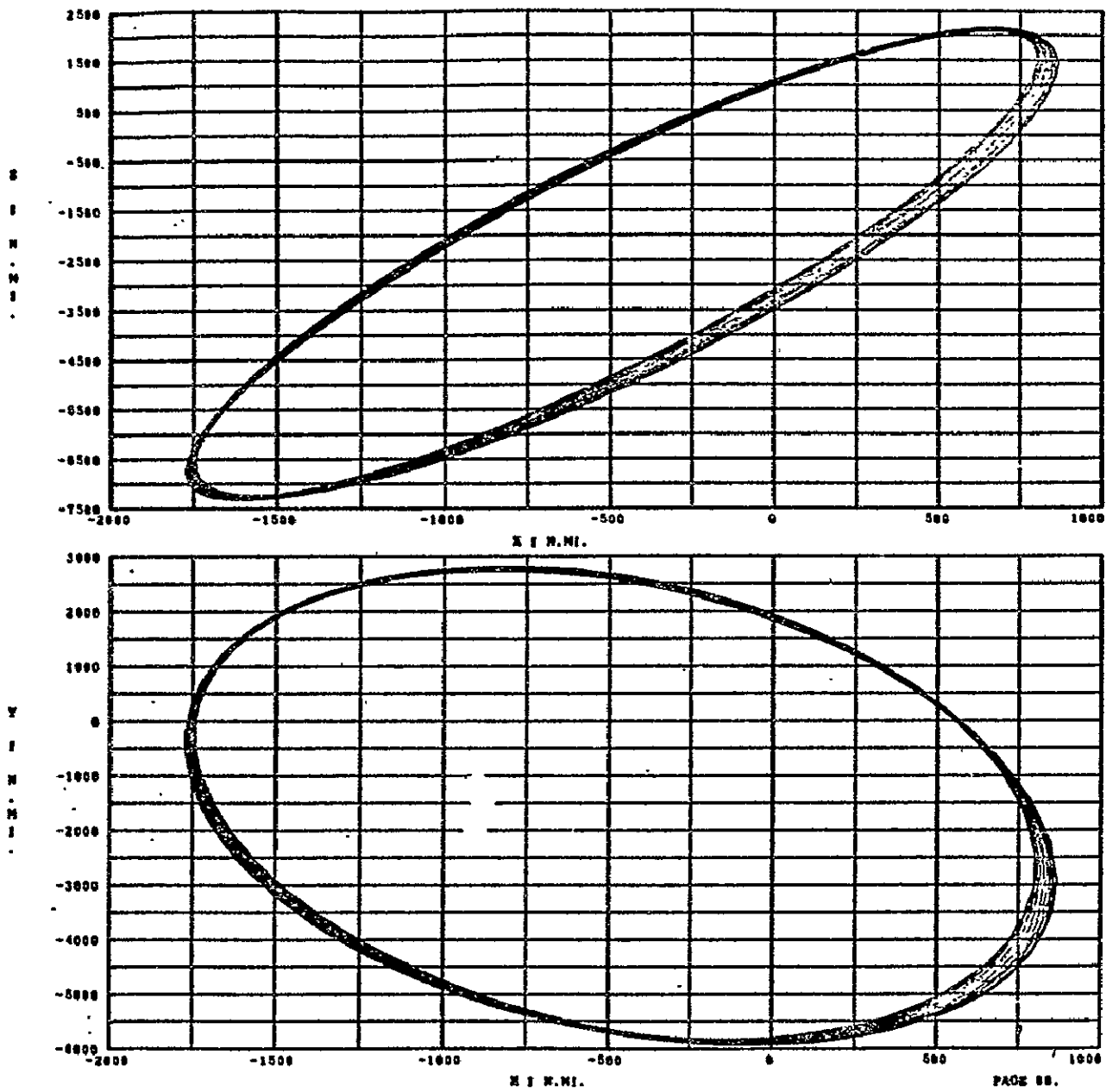
(e) Trajectory projections on the X-Y and X-Z planes.

Figure 12.- Continued.



(e) Trajectory projections on the X-Y and X-Z planes - continued.

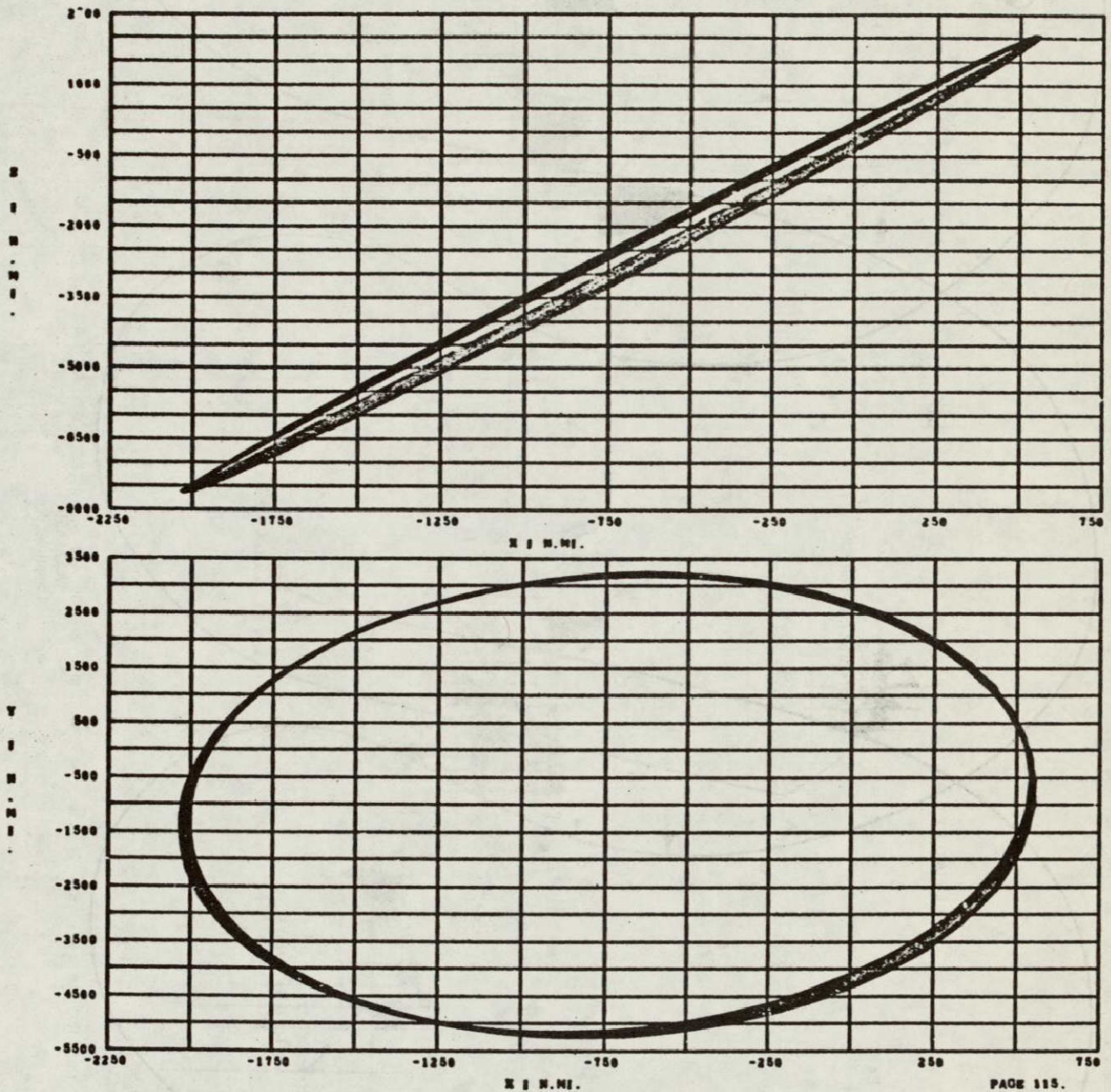
Figure 12.- Continued.



(e) Trajectory projections on the X-Y and X-Z planes - continued.

Figure 12.- Continued.



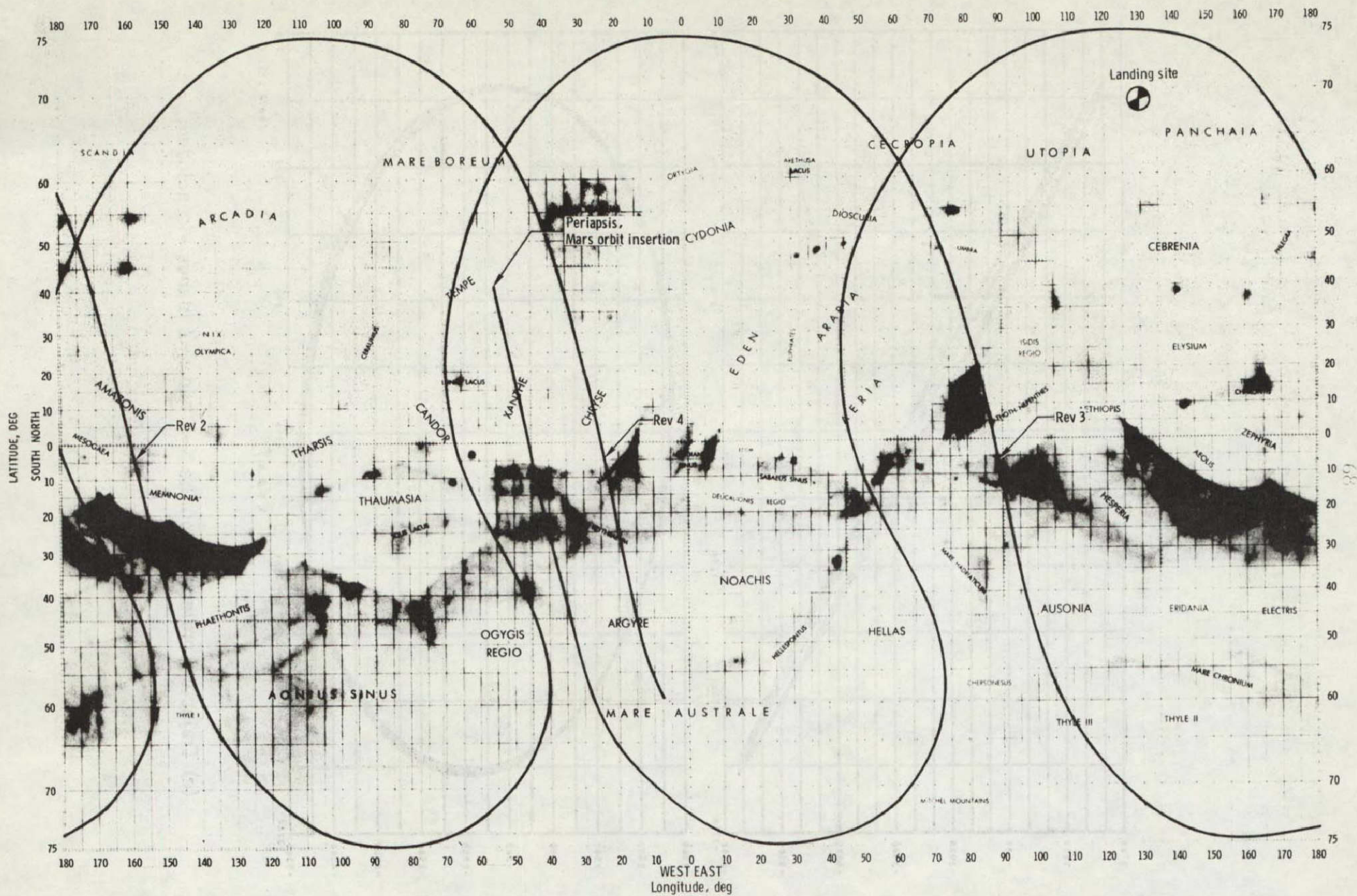


(e) Trajectory projections on the X-Y and X-Z planes - concluded.

Figure 12.- Concluded.



# MARS PLANNING CHART

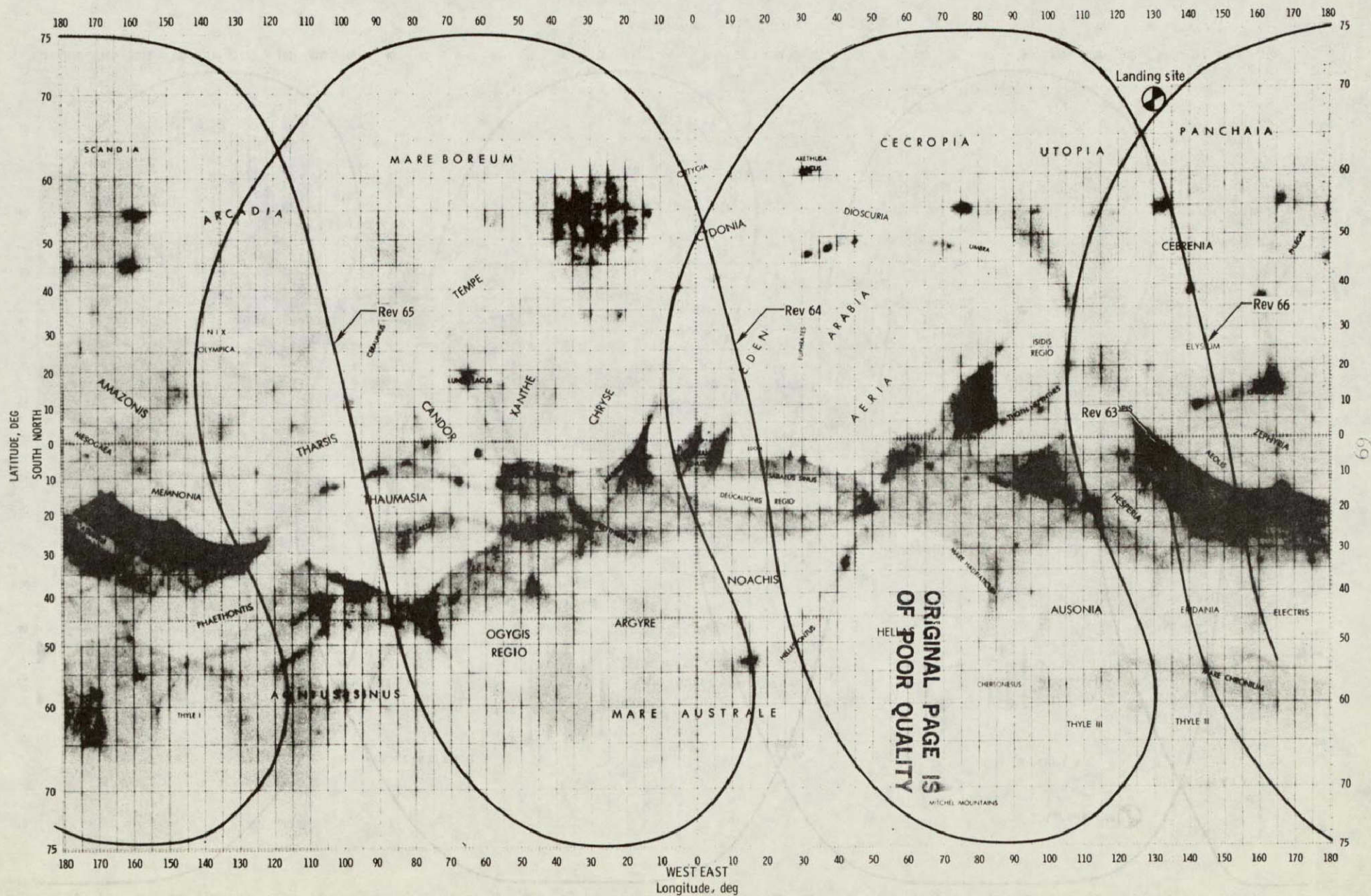


(a) First day after MOI (revolutions 1 thru 4).

Figure 13. - Parking orbit groundtrack.

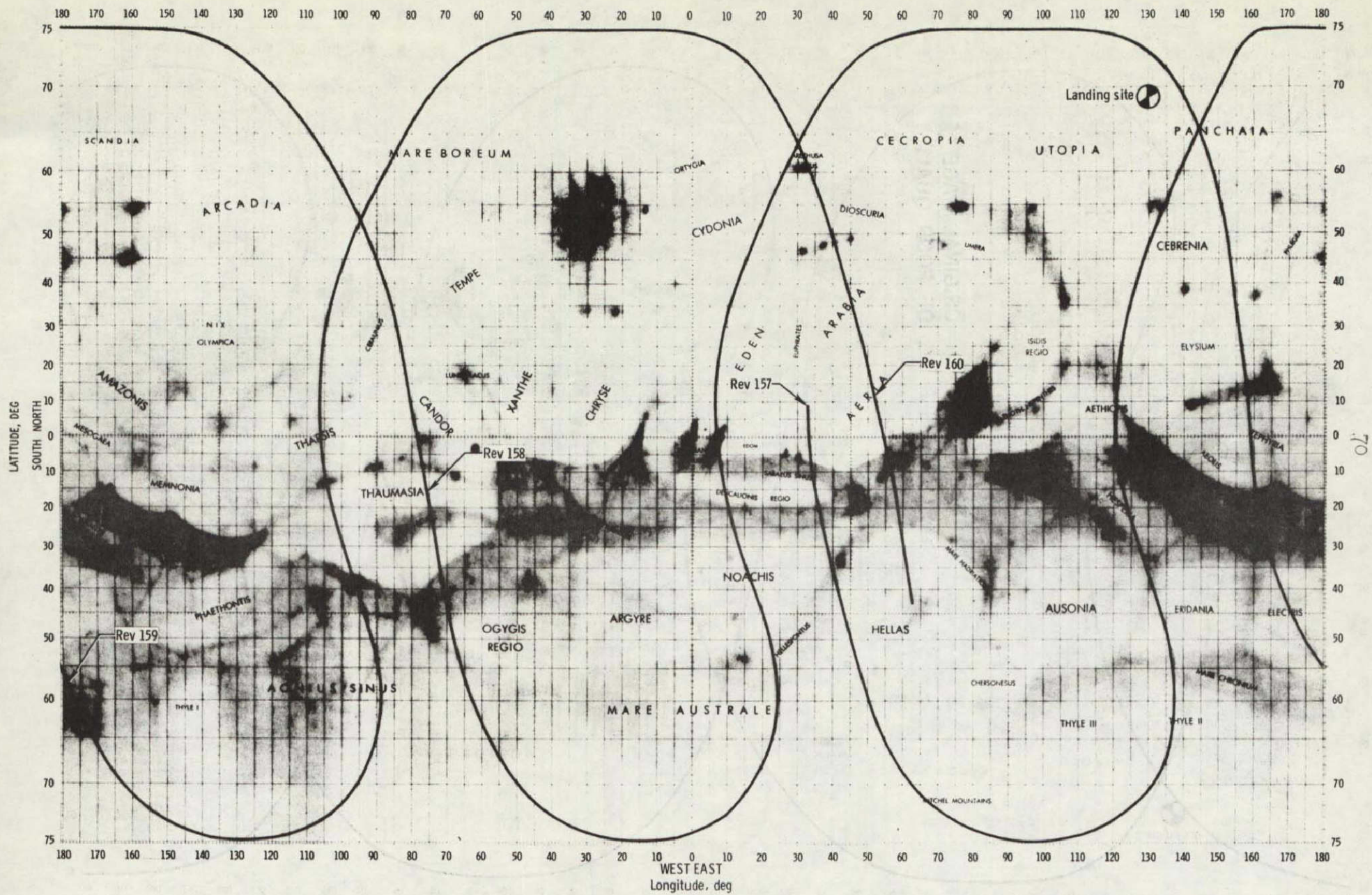


# MARS PLANNING CHART





## MARS PLANNING CHART

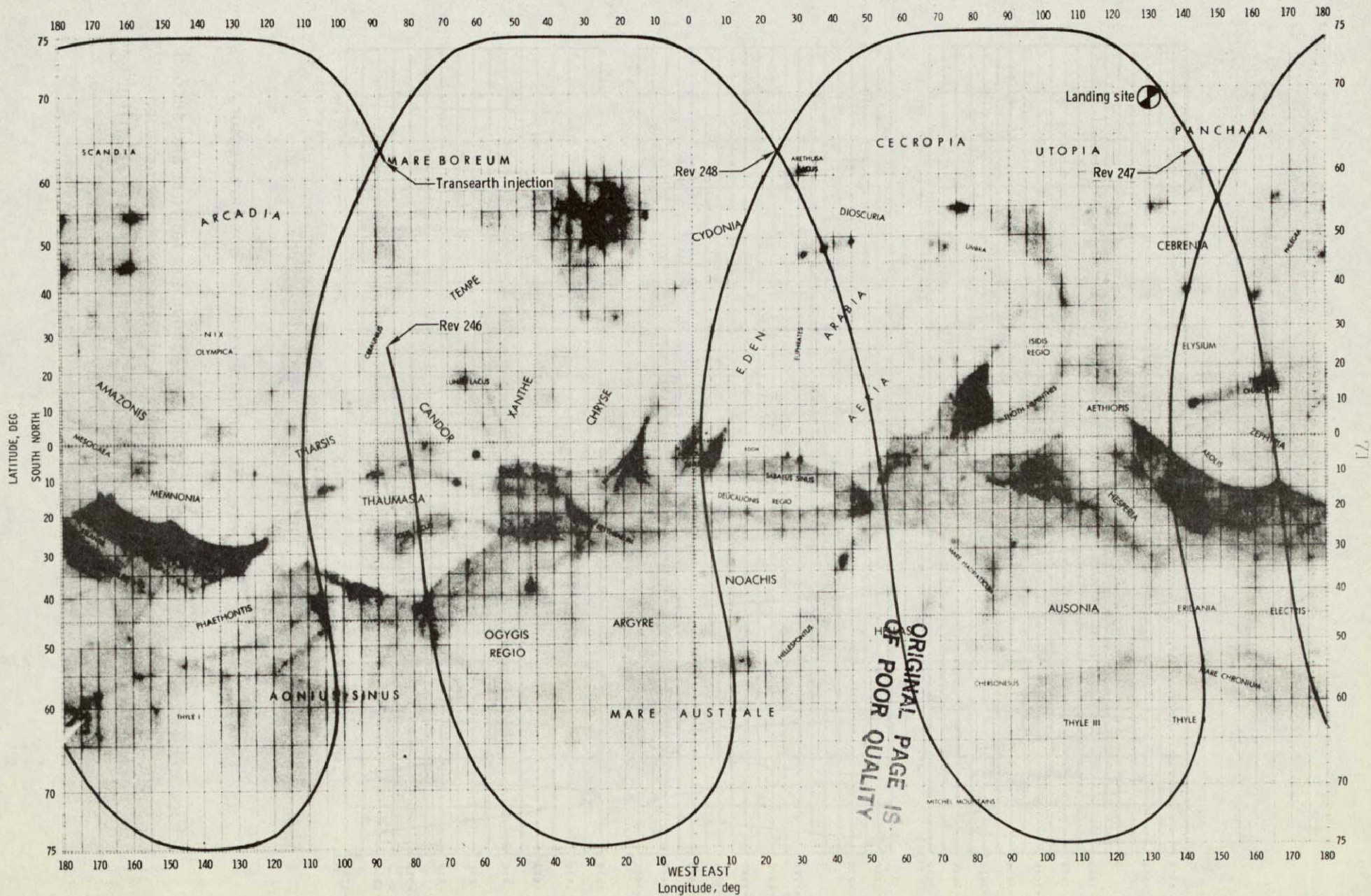


(c) Fiftieth day after MOI (157 thru 160).

Figure 13. - Continued.

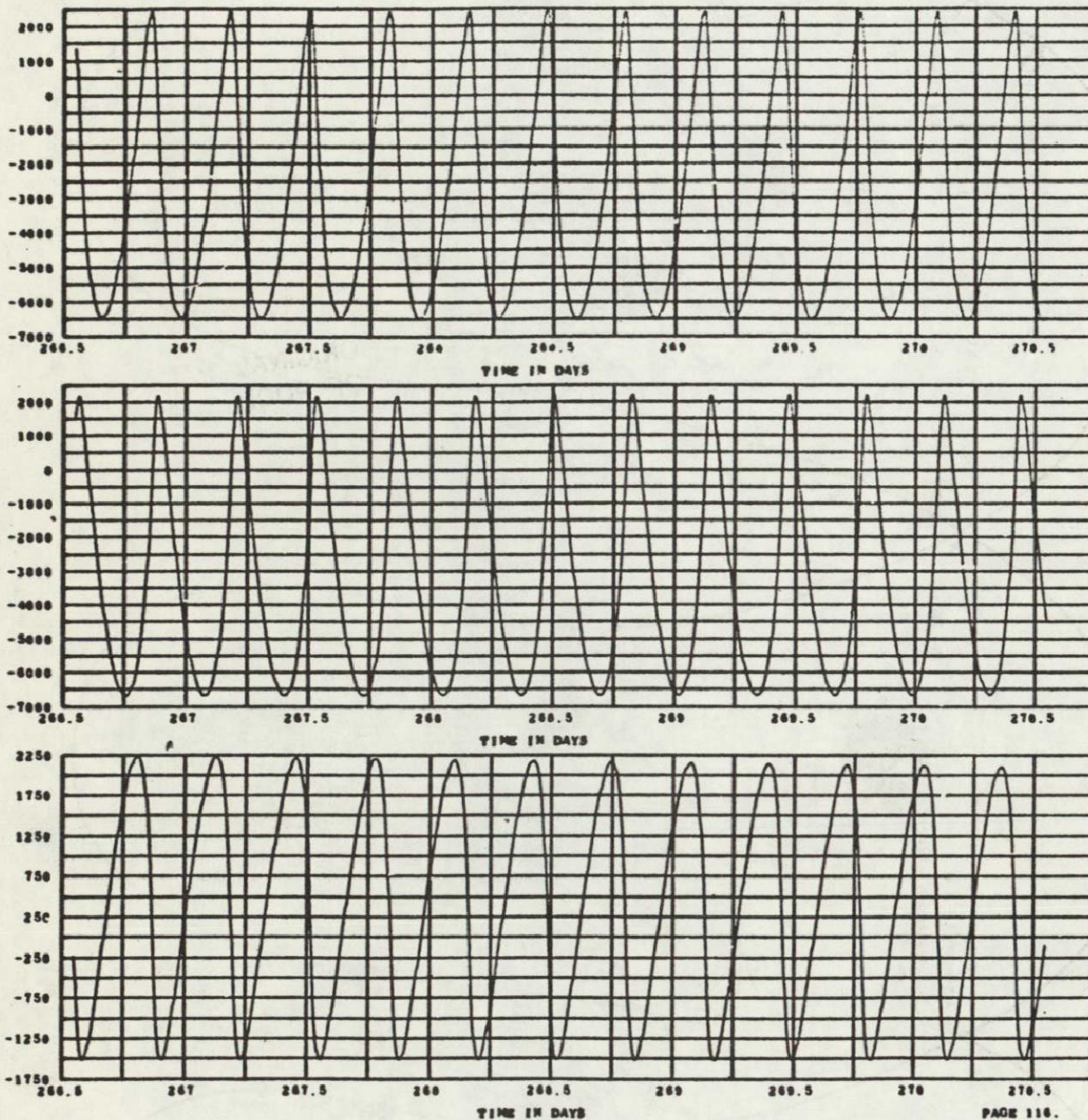


## MARS PLANNING CHART



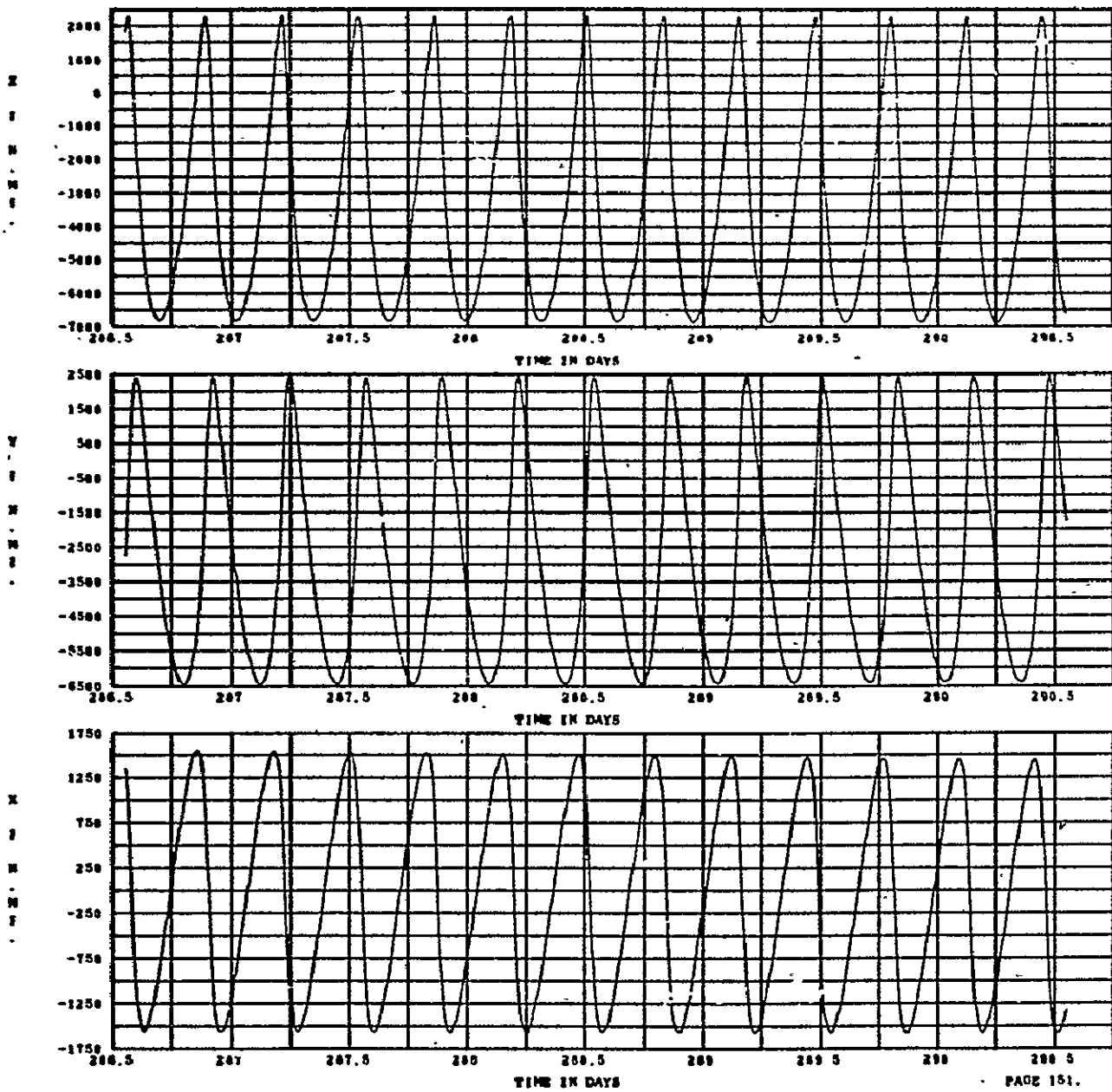
(d) Seventy-ninth day after MOI (revolutions 246 thru 248).





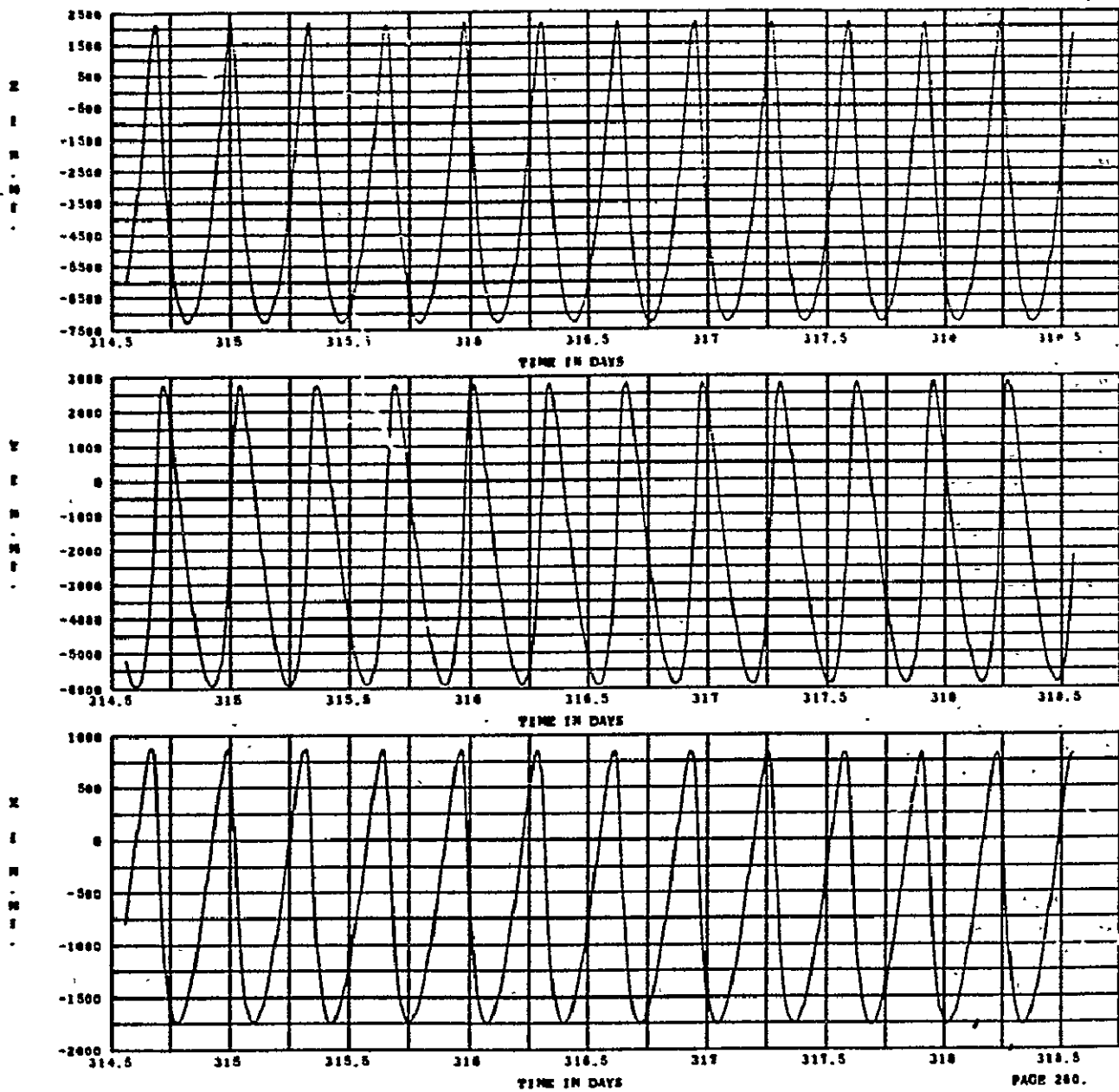
(a) Time histories of the Cartesian components of the position vector.

Figure 14.- Mars orbit trajectory parameters accounting for first and second order secular as well as first order short and long period perturbations (areocentric or Mars equatorial coordinate systems) periapsis at arrival propagated for an 80-day stay.



(a) Time histories of the Cartesian components of the position vector - continued,

Figure 14.- Continued.

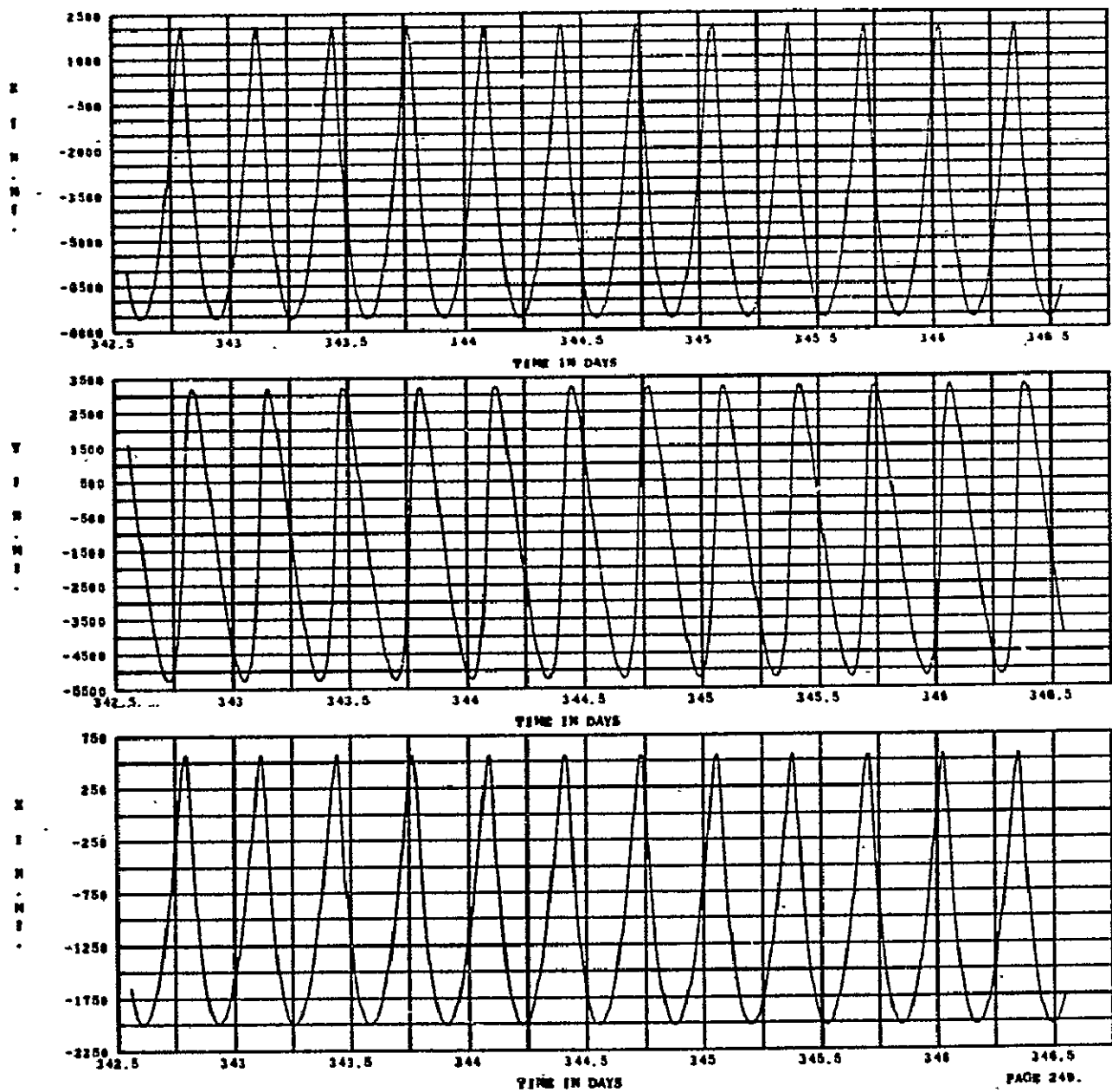


PAGE 280.

(a) Time histories of the Cartesian components of the position vector - continued.

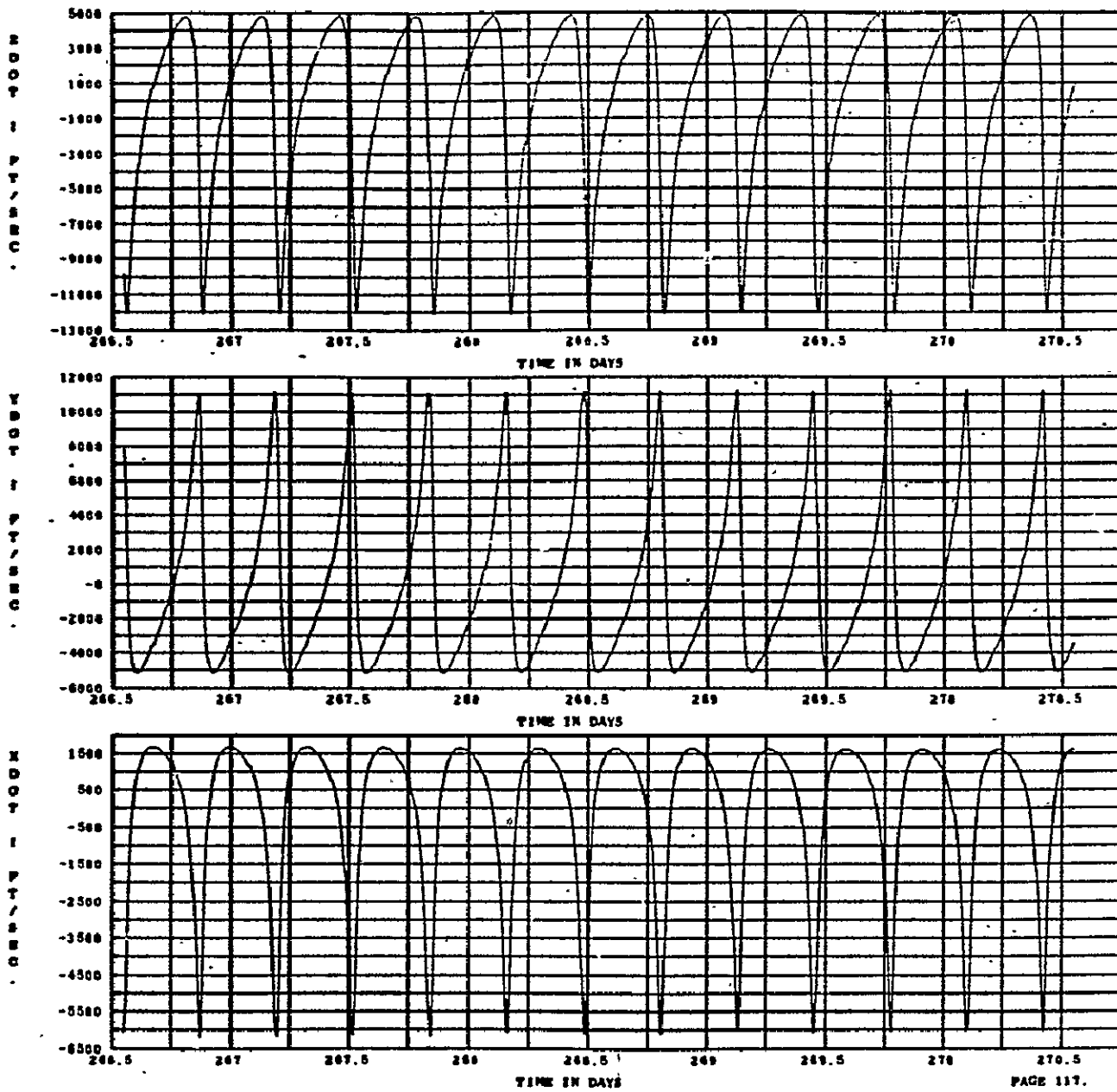
Figure 14.- Continued.





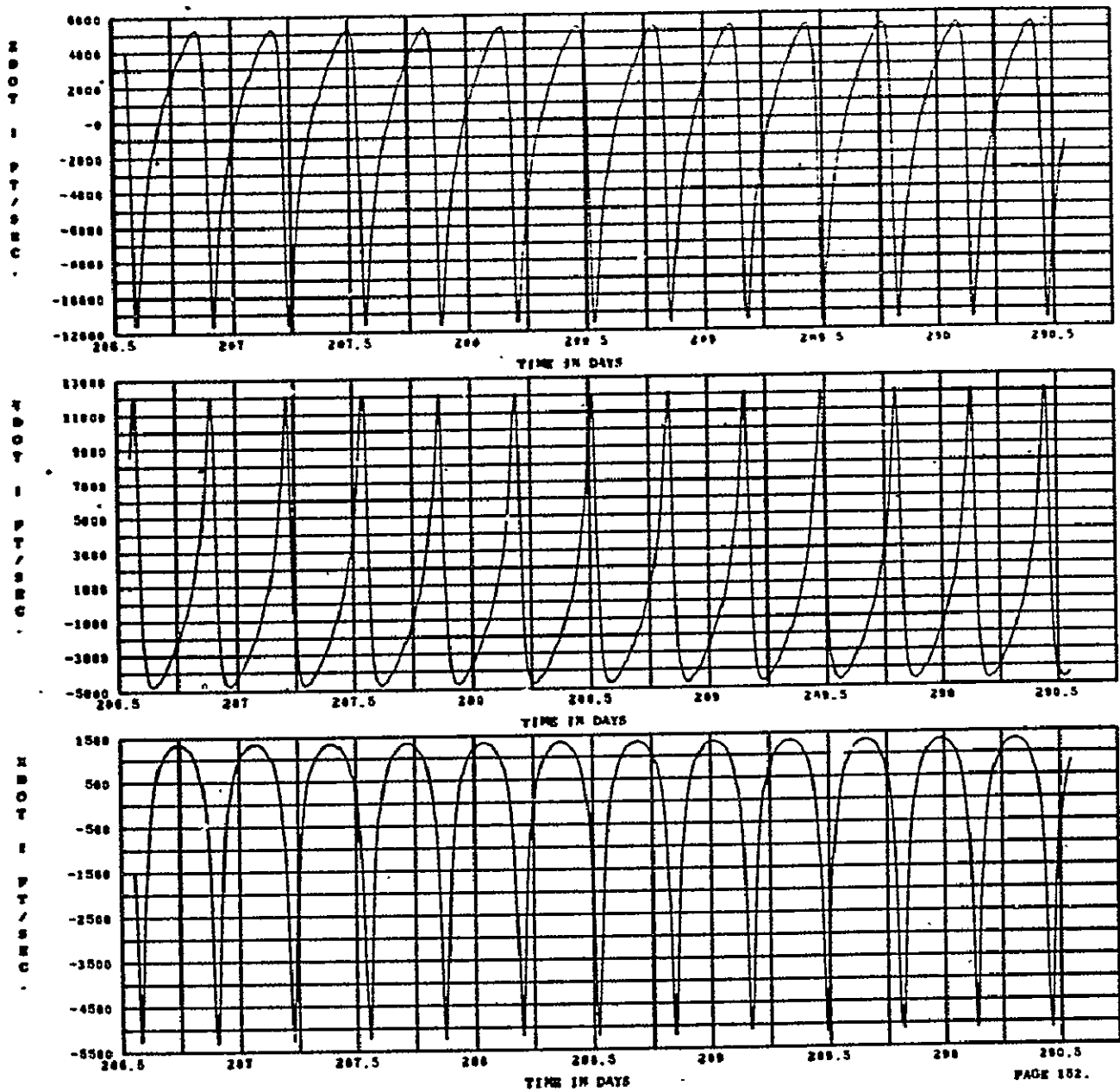
(a) Time histories of the Cartesian components of the position vector - concluded.

Figure 14.- Continued.



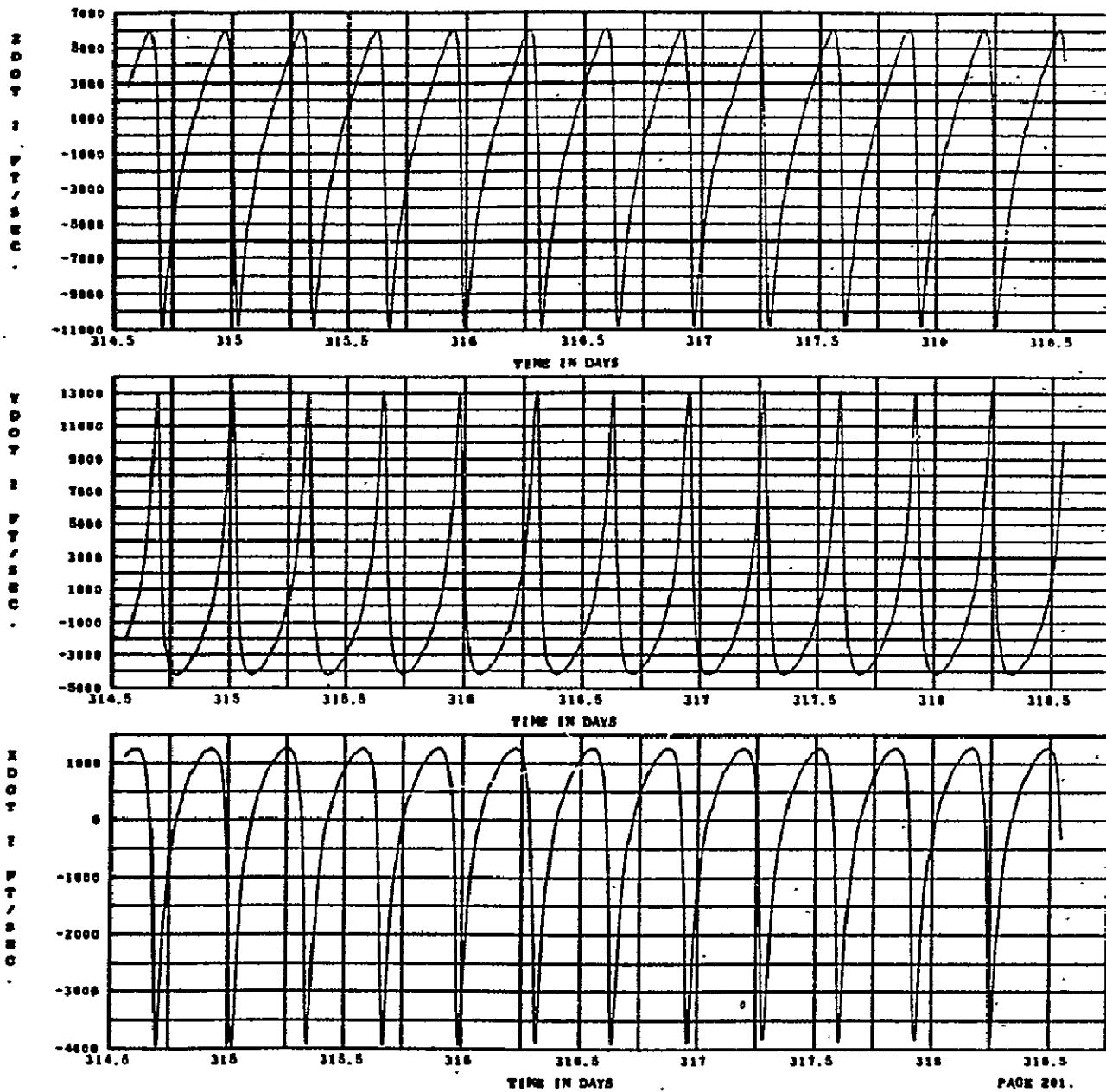
(b) Time histories of the Cartesian components of the velocity vector.

Figure 14.- Continued.



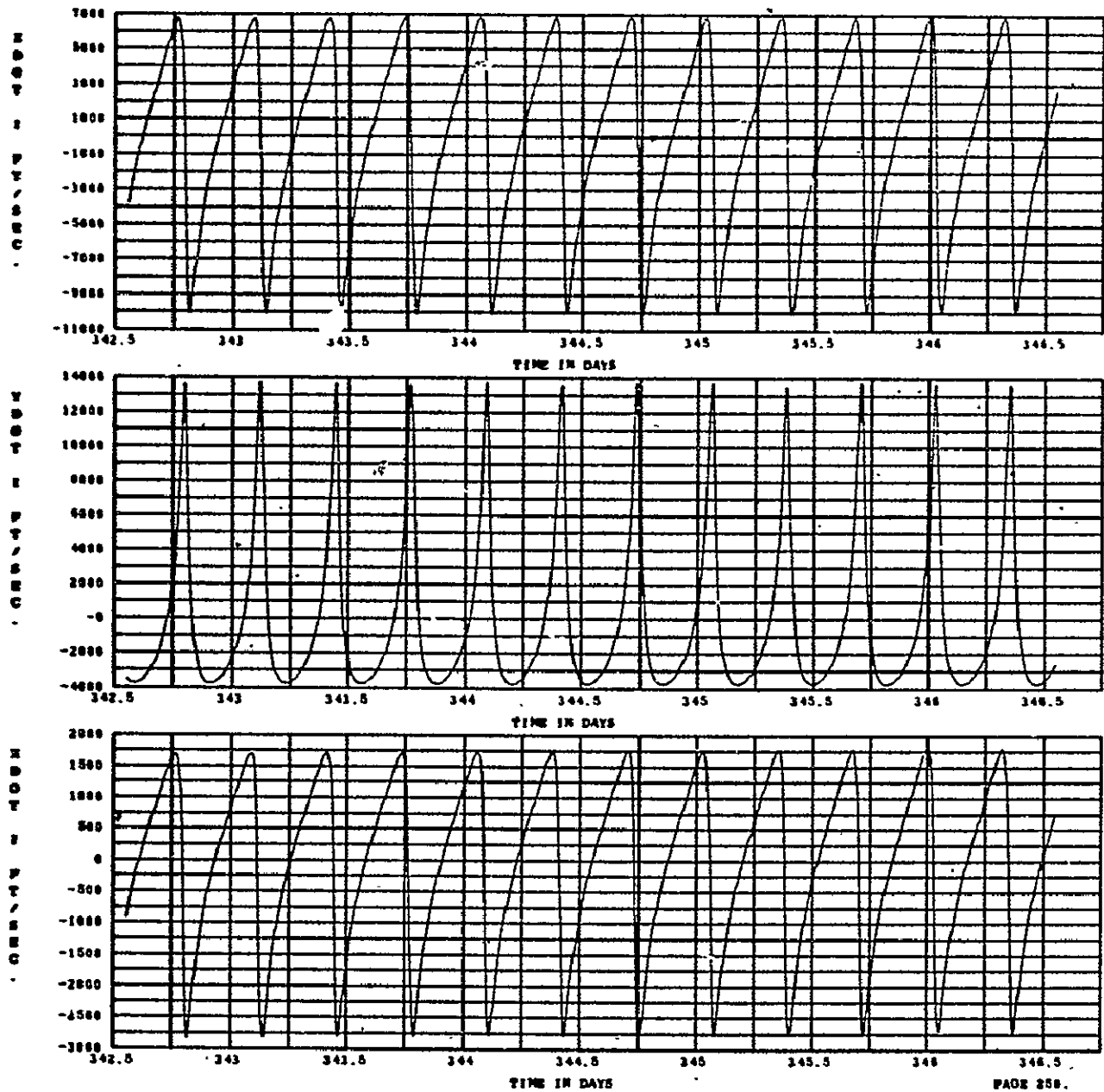
(b) Time histories of the Cartesian components of the velocity vector - continued.

Figure 14.- Continued.



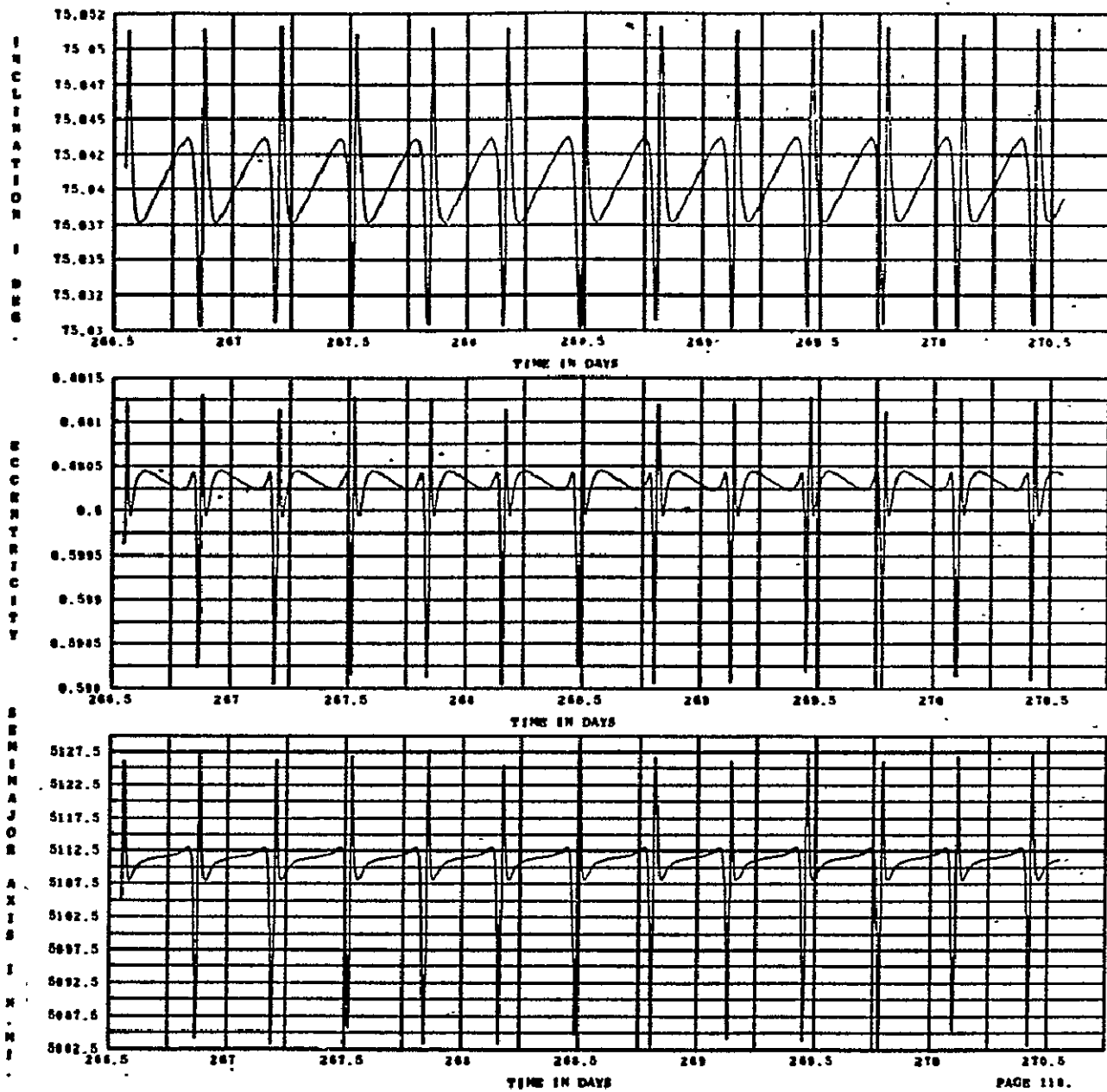
(b) Time histories of the Cartesian components of the velocity vector - continued.

Figure 14.- Continued.



(b) Time histories of the Cartesian components of the velocity vector - concluded.

Figure 14.- Continued.

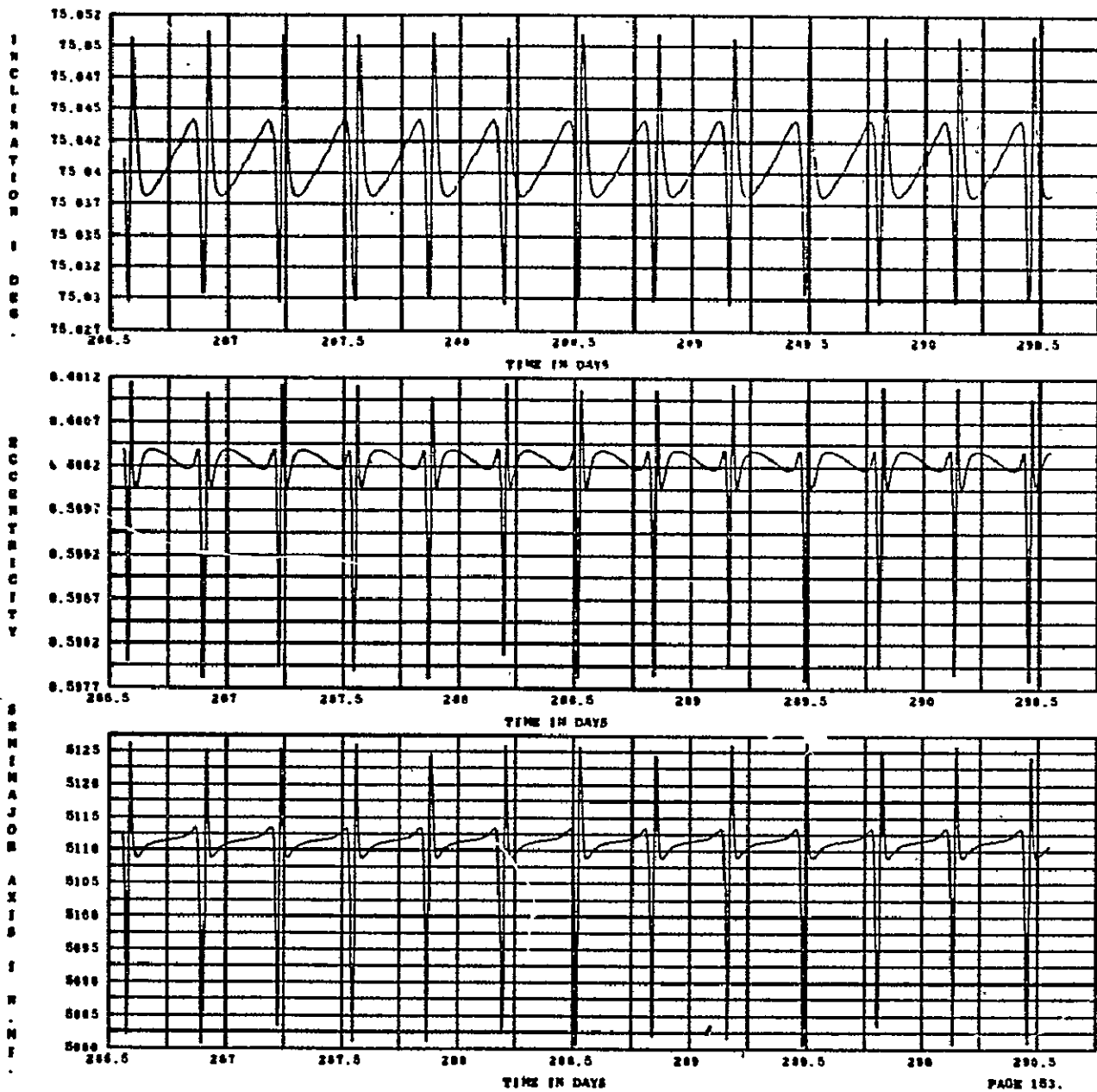


(c) Time histories of the orbital elements

Figure 14.- Continued.

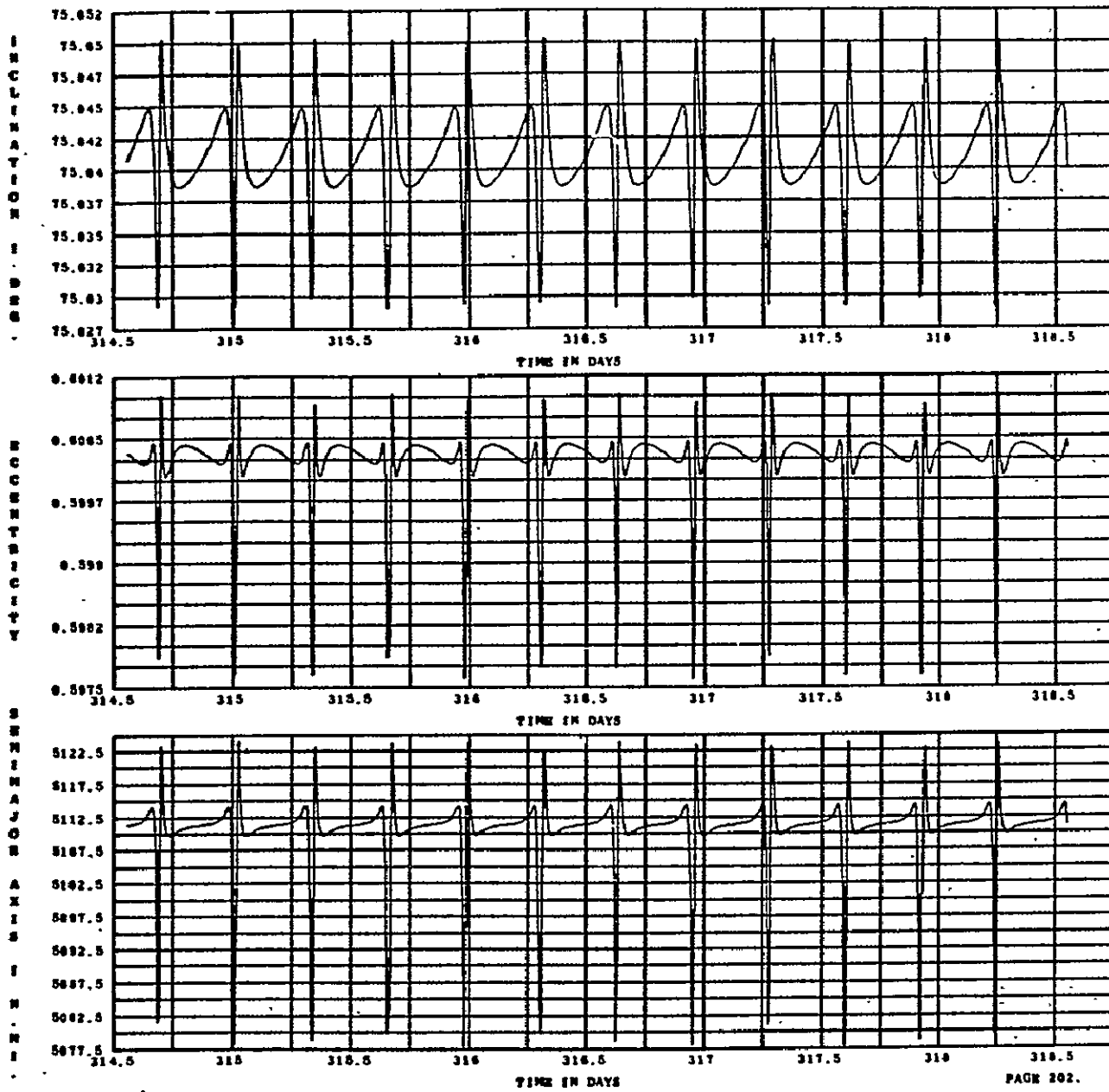
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(c) Time histories of the orbital elements - continued.

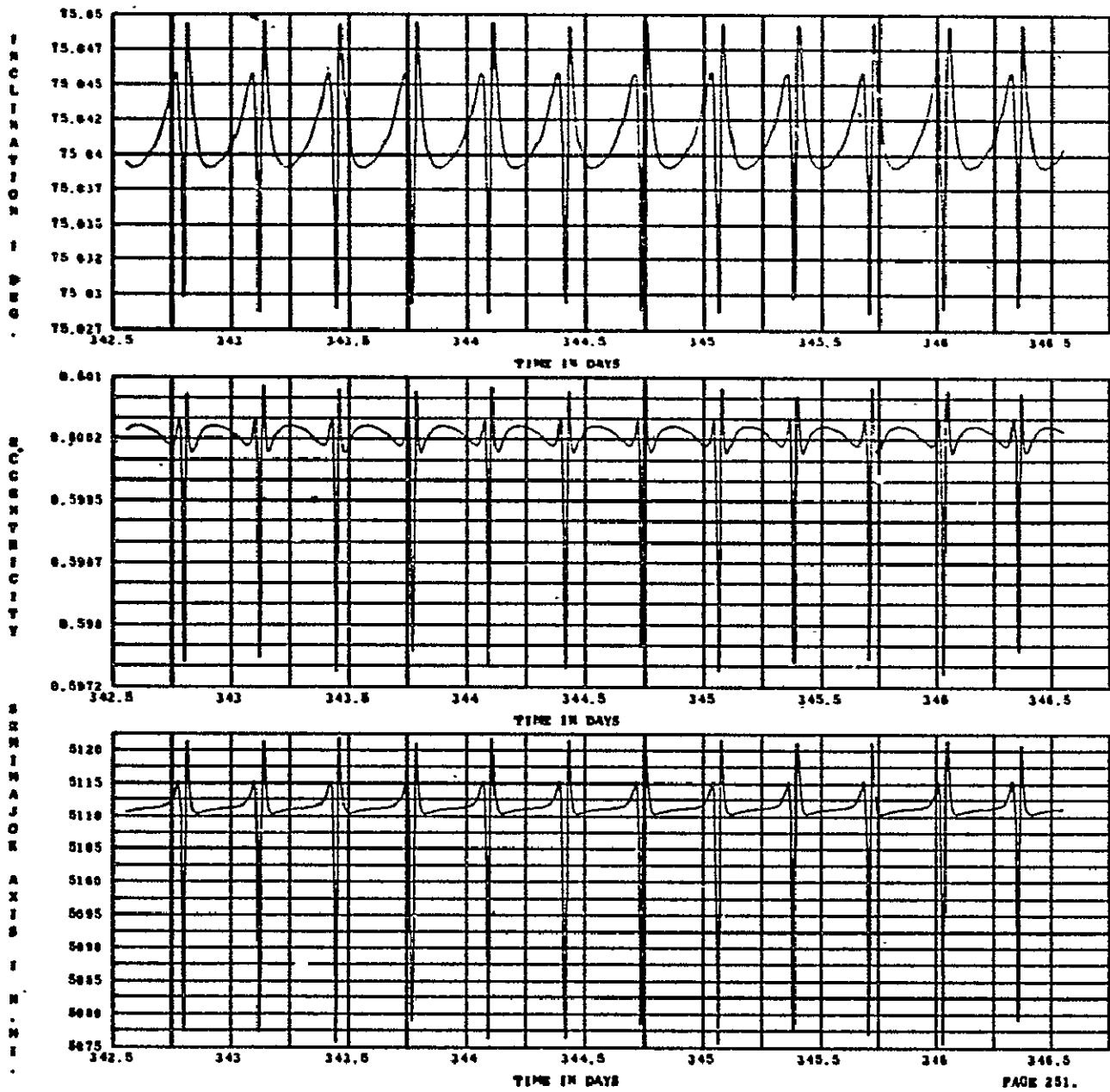
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(c) Time histories of the orbital elements - continued.

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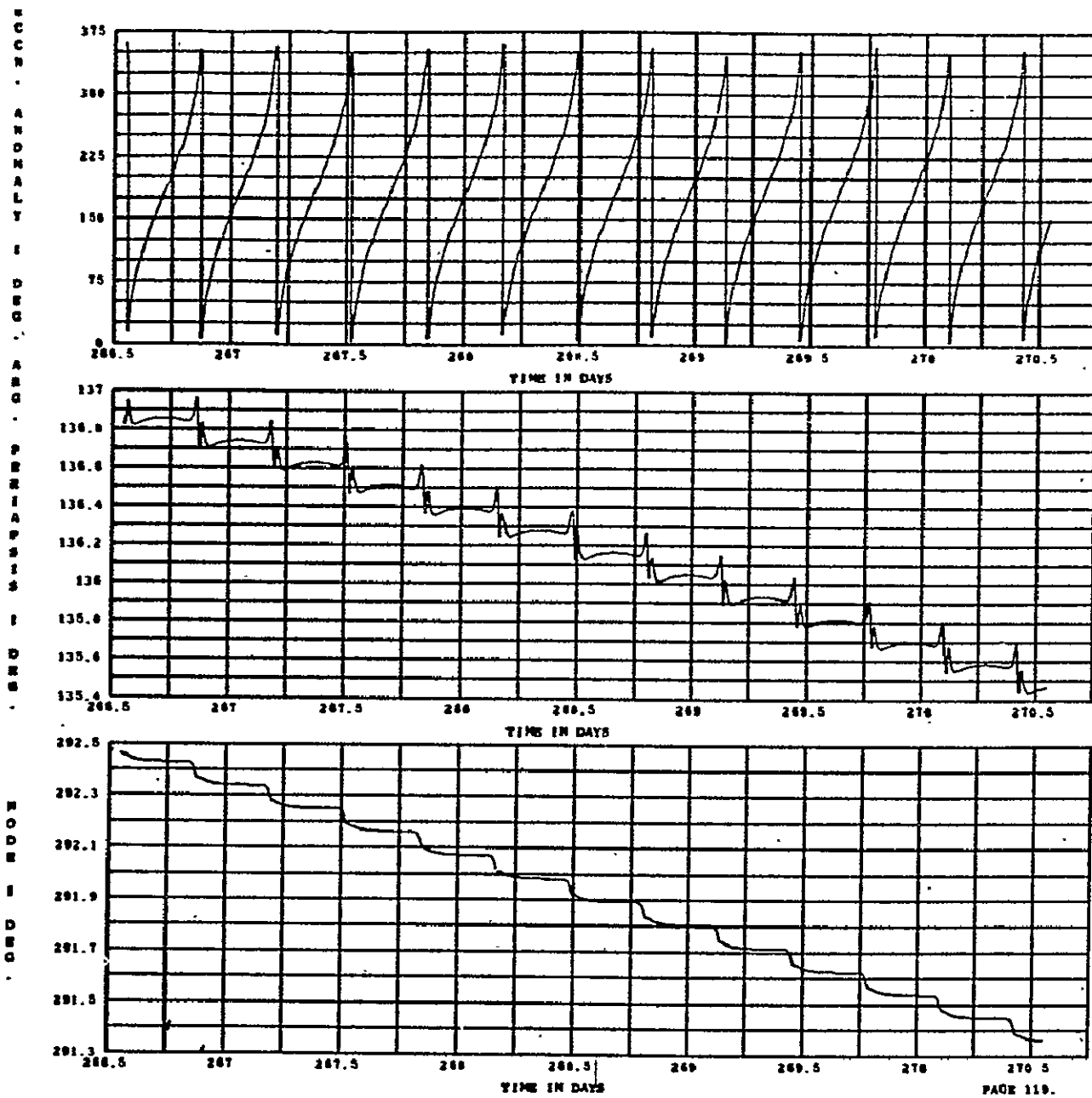




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(c) Time histories of the orbital elements - concluded.

Figure 14.- Continued.



(d) Time histories of the orbital elements.

Figure 14.- Continued.

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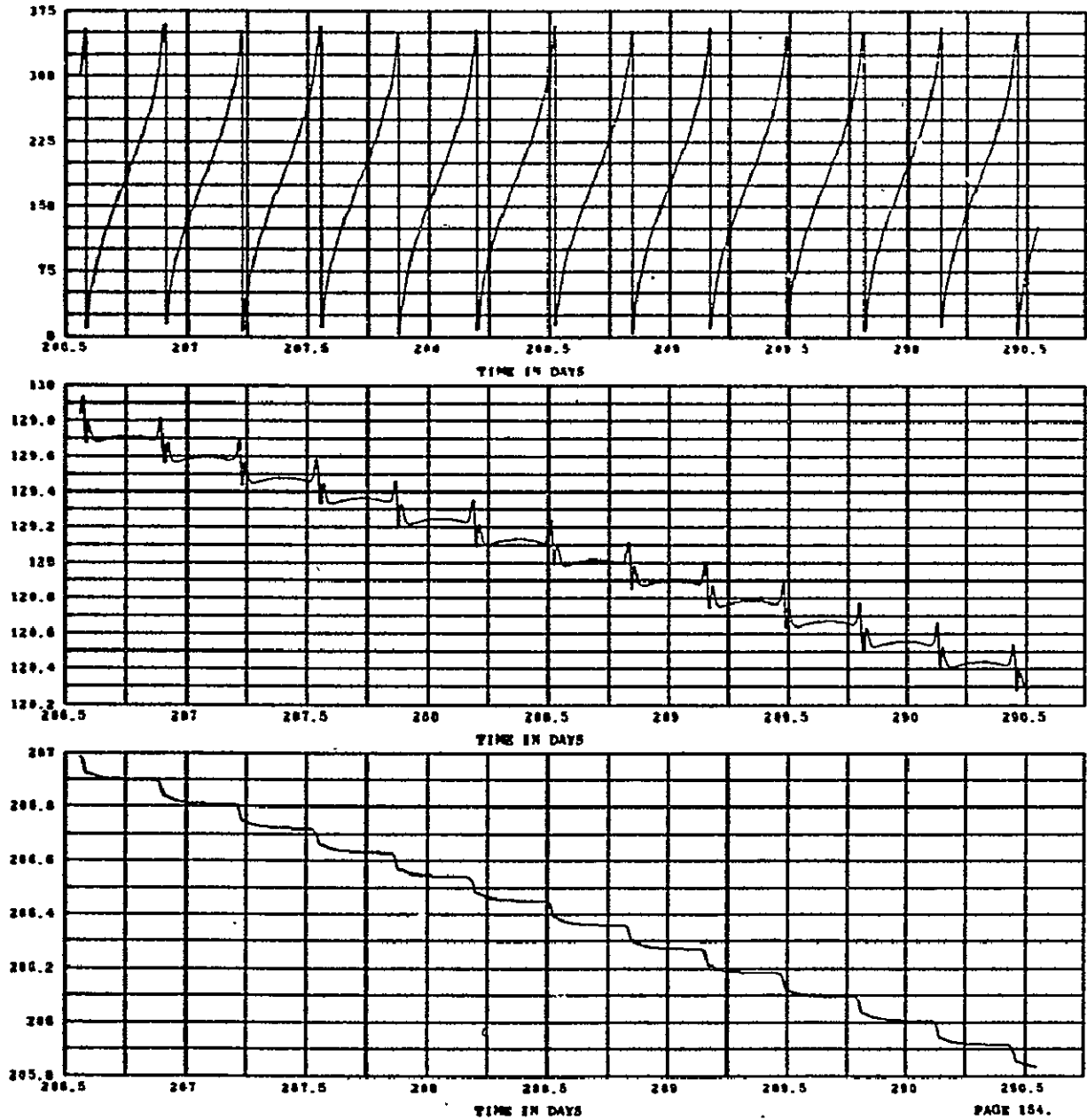
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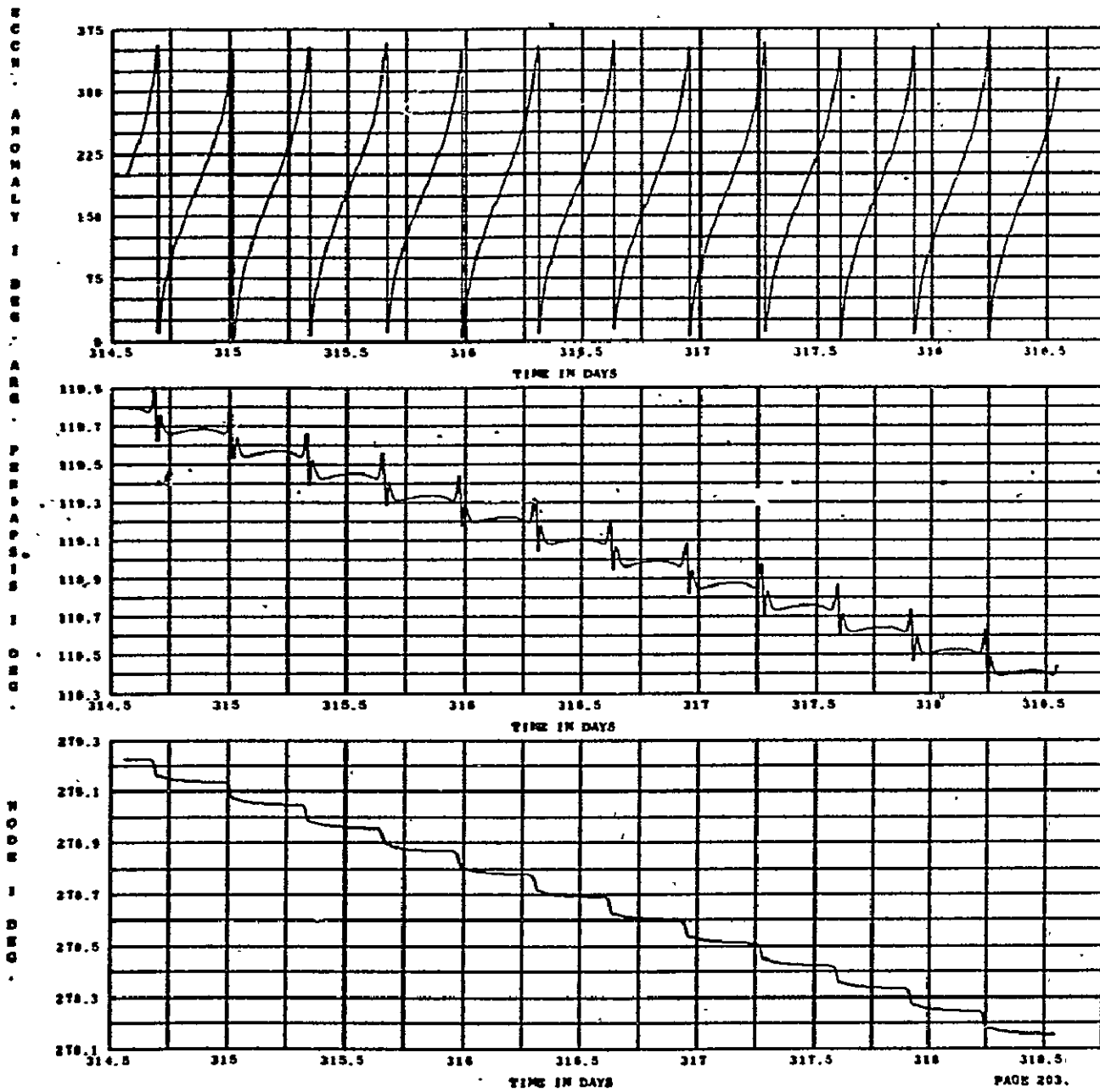
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(d) Time histories of the orbital elements - continued.

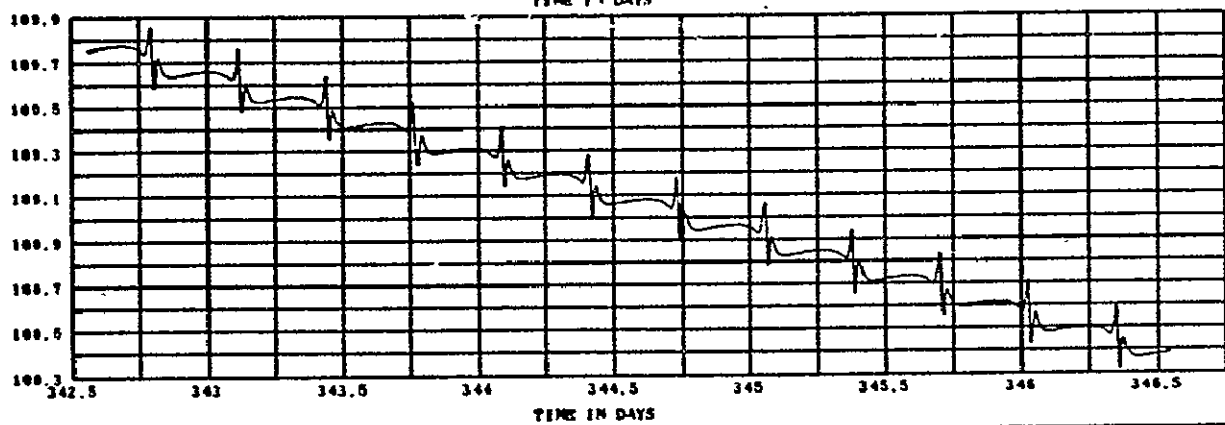
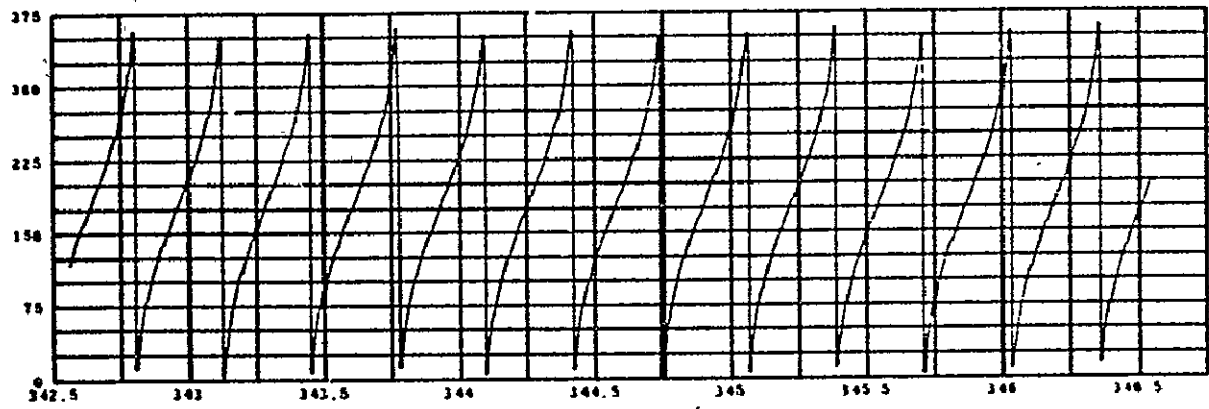
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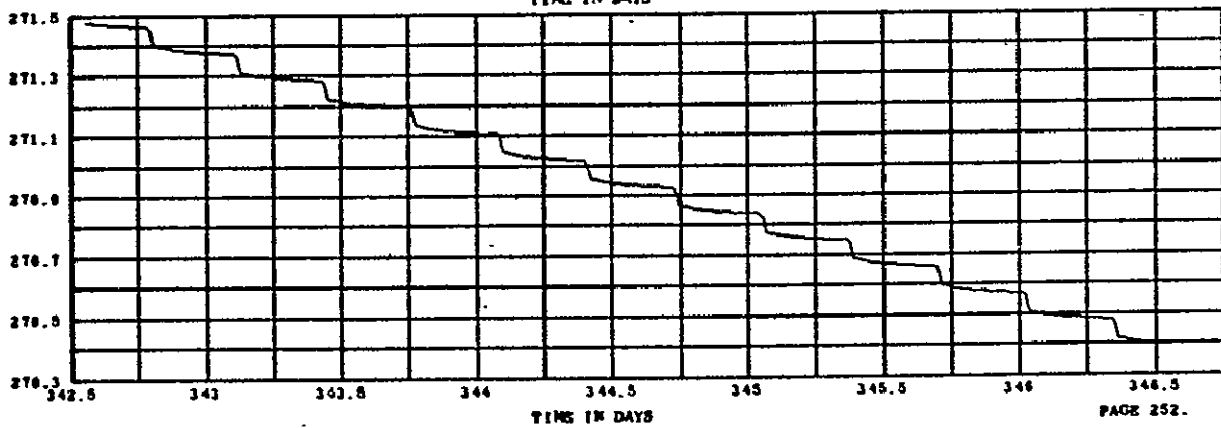
(d) Time histories of the orbital elements - continued.

Figure 14.- Continued.

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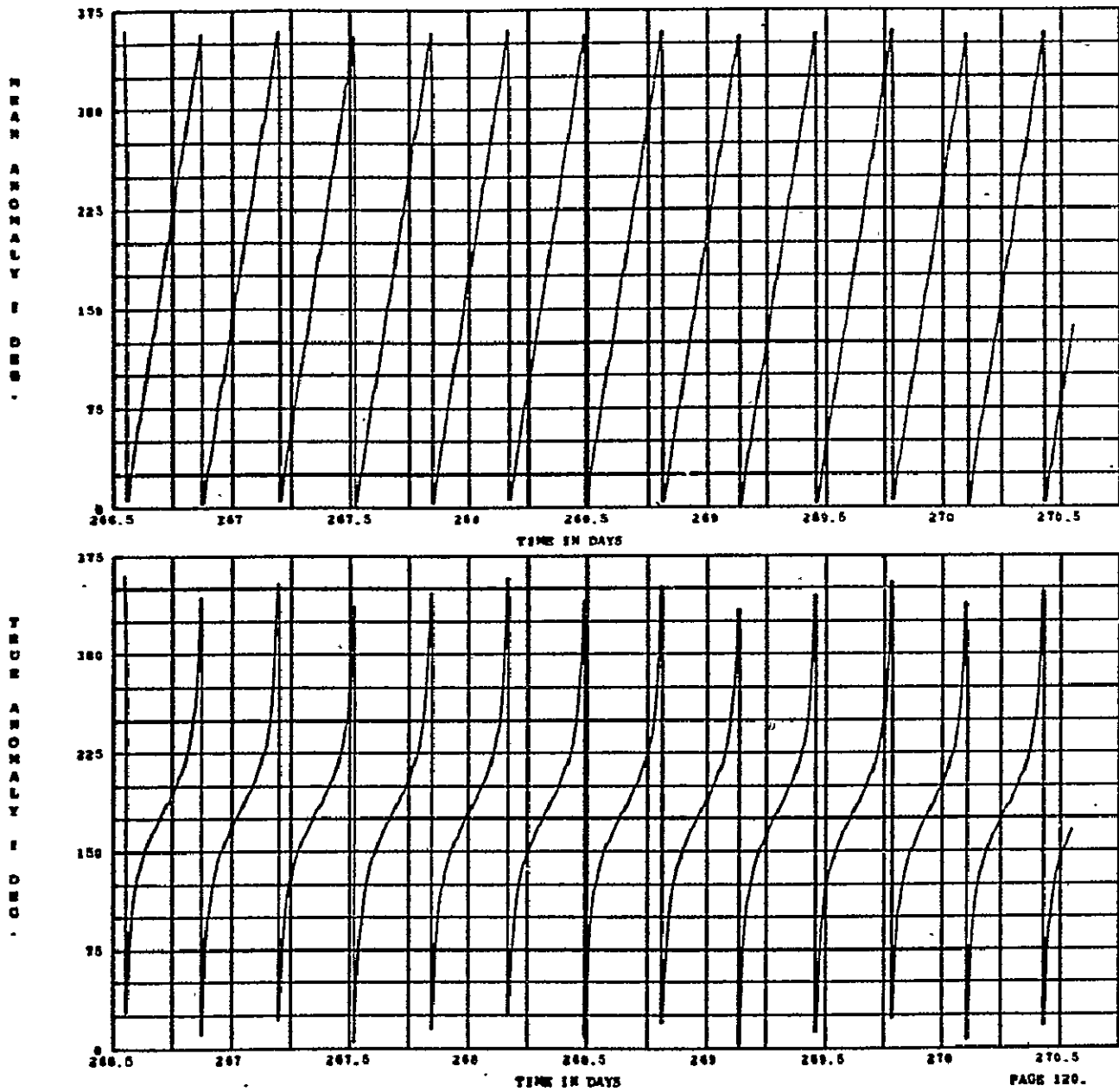
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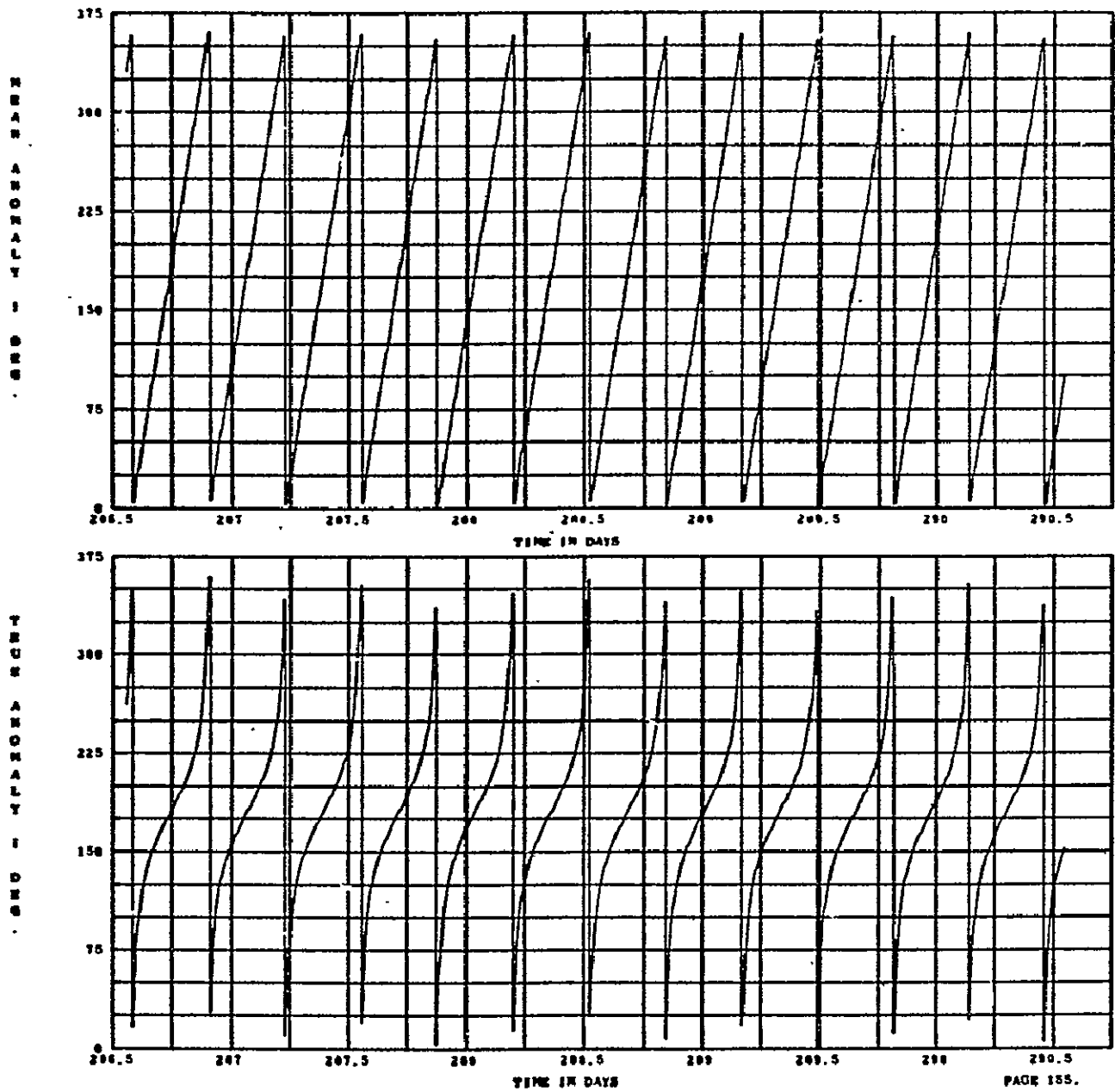
(d) Time histories of the orbital elements - concluded.

Figure 14.- Continued.



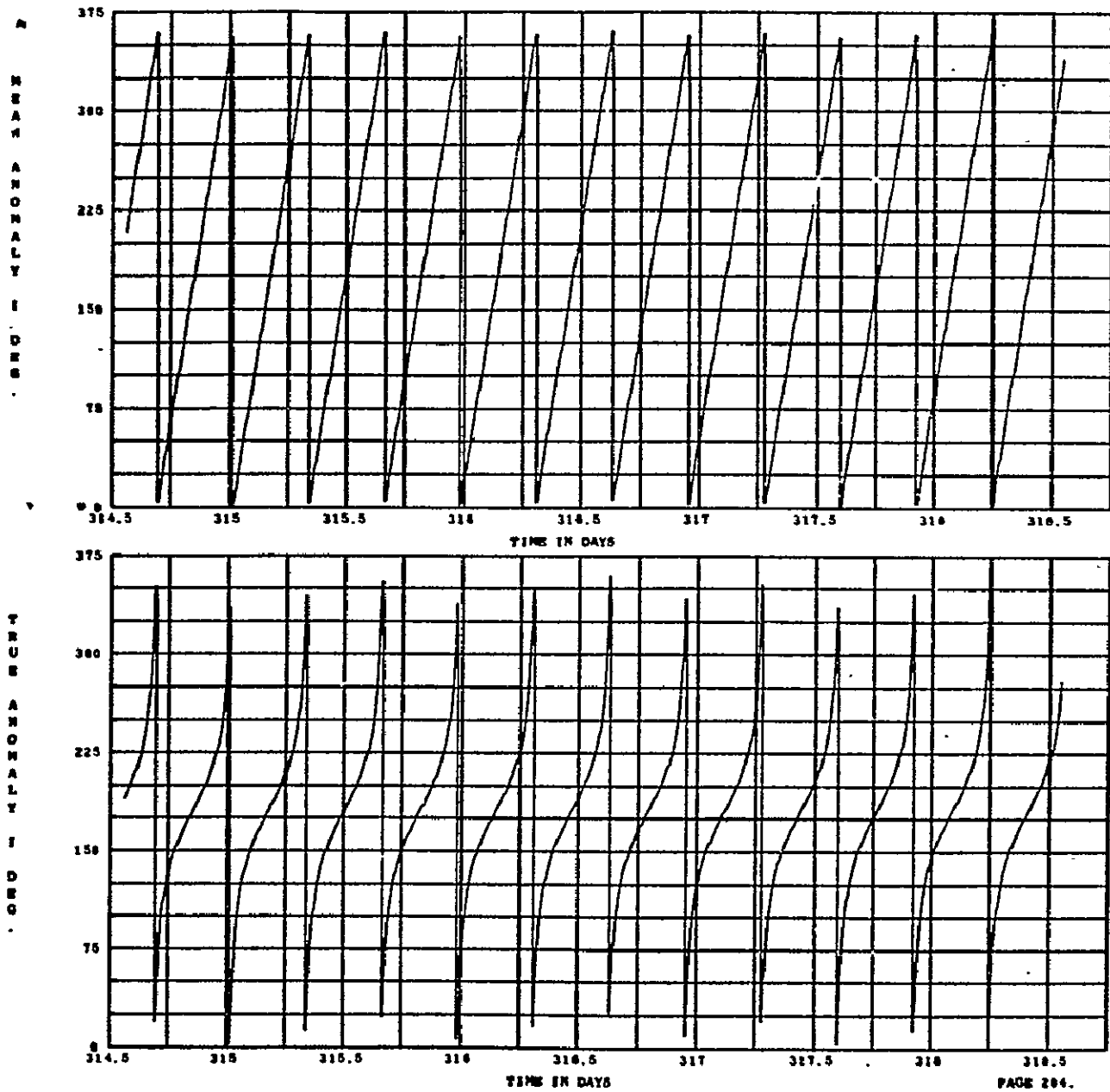
(e) Time histories of the true anomaly and mean anomaly.

Figure 14.- Continued.



(e) Time histories of the true anomaly and mean anomaly - continued.

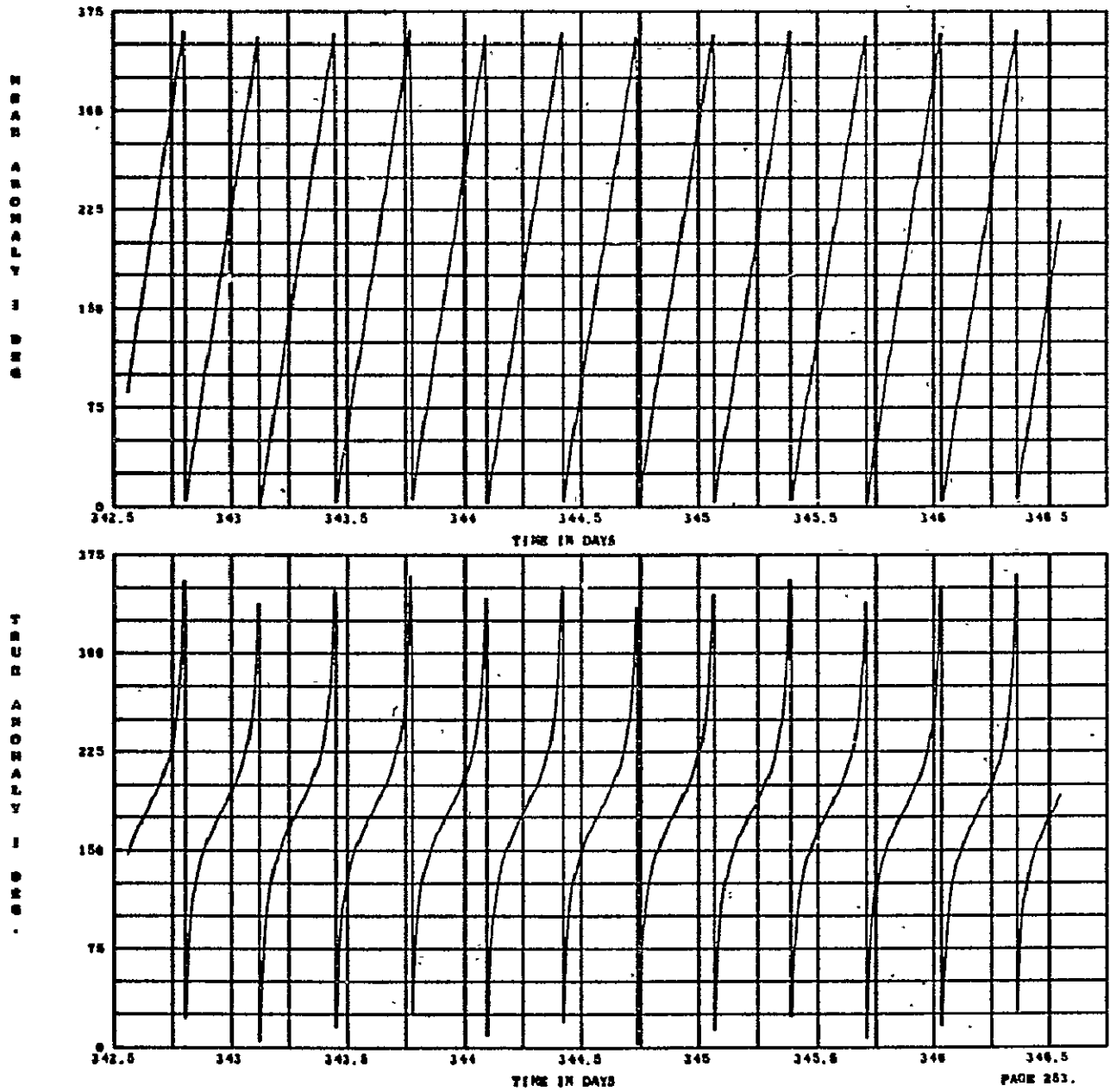
Figure 14.- Continued.



(e) Time histories of the true anomaly and mean anomaly - continued.

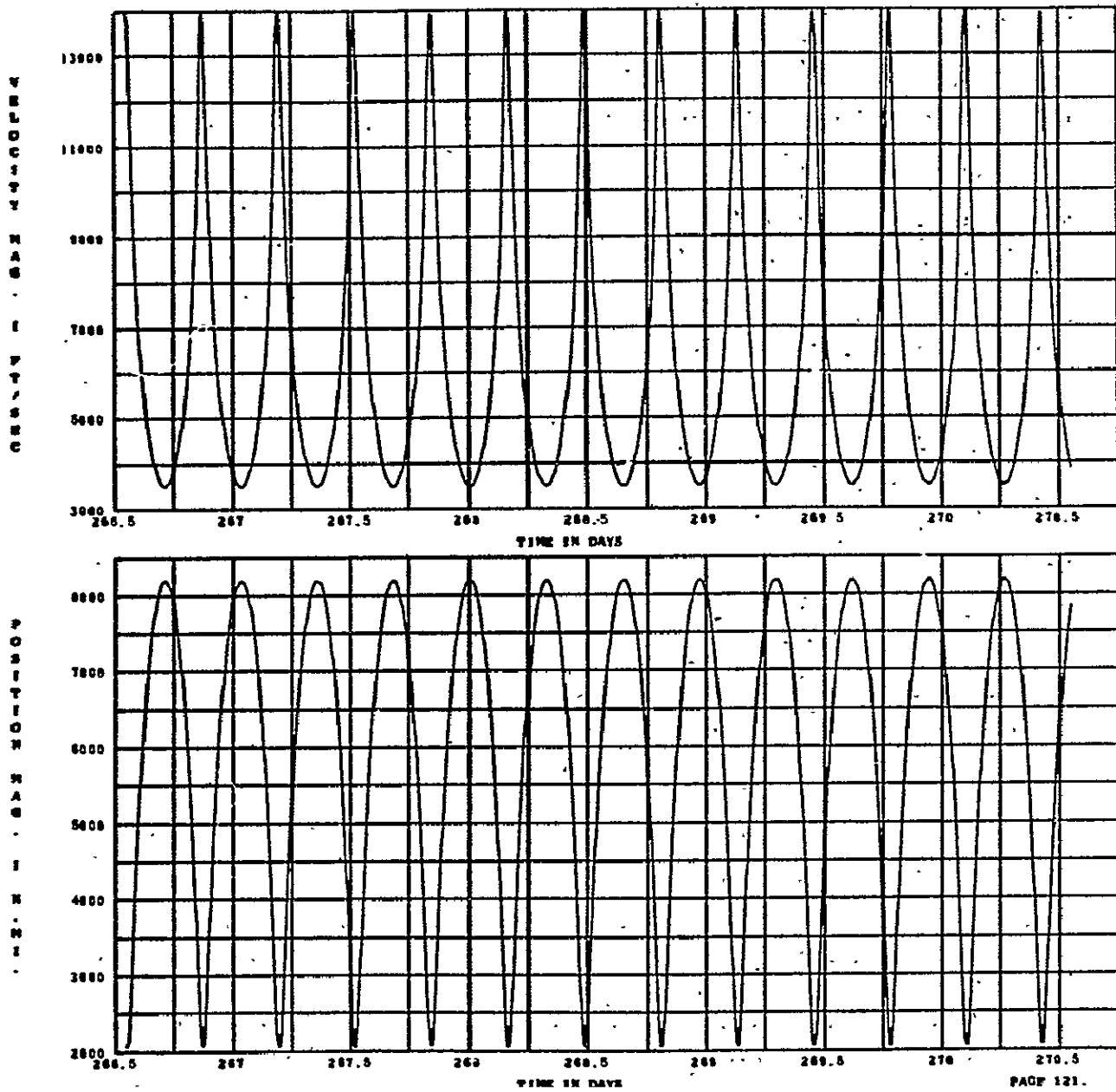
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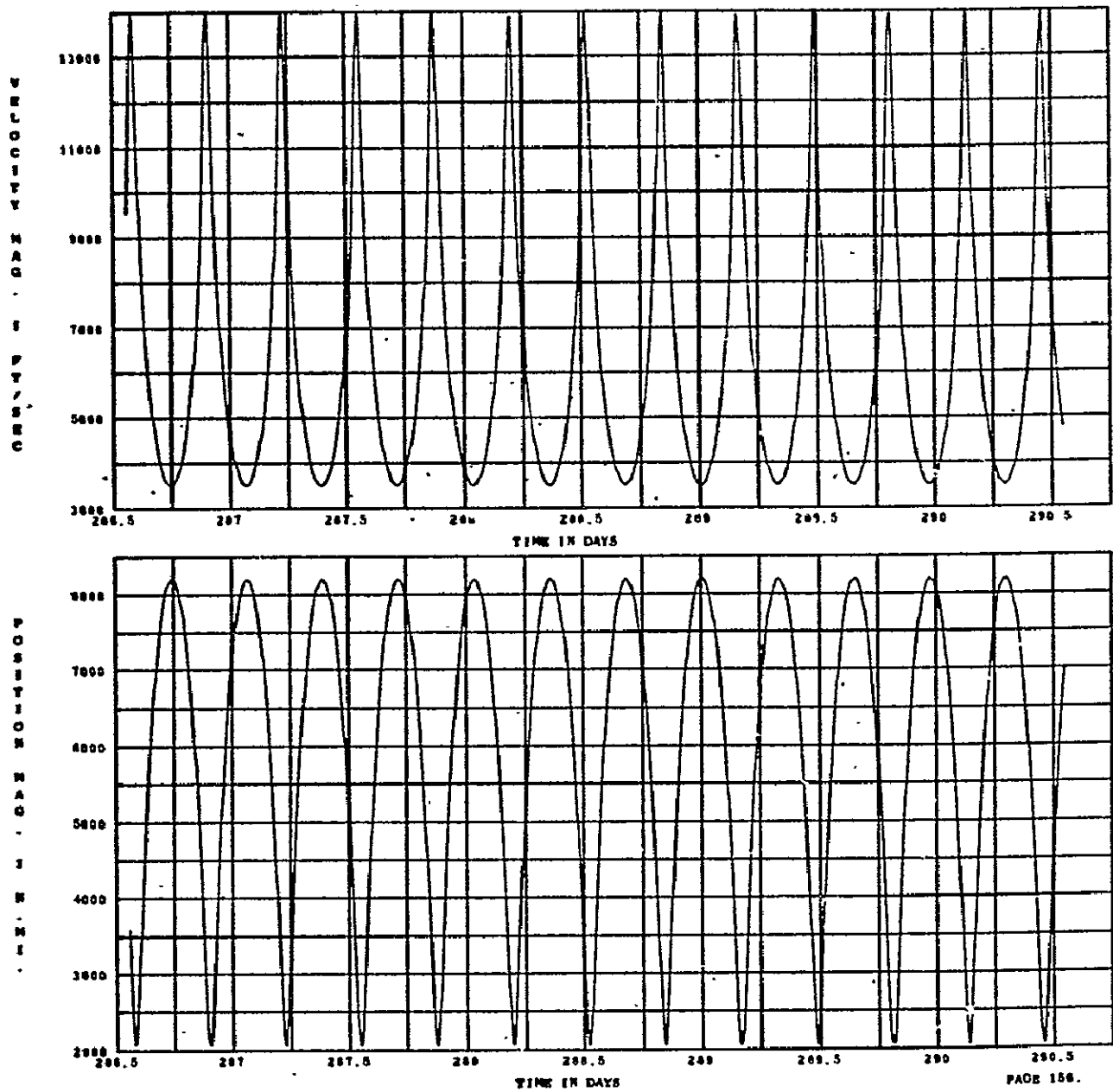
(e) Time histories of the true anomaly and mean anomaly - concluded.

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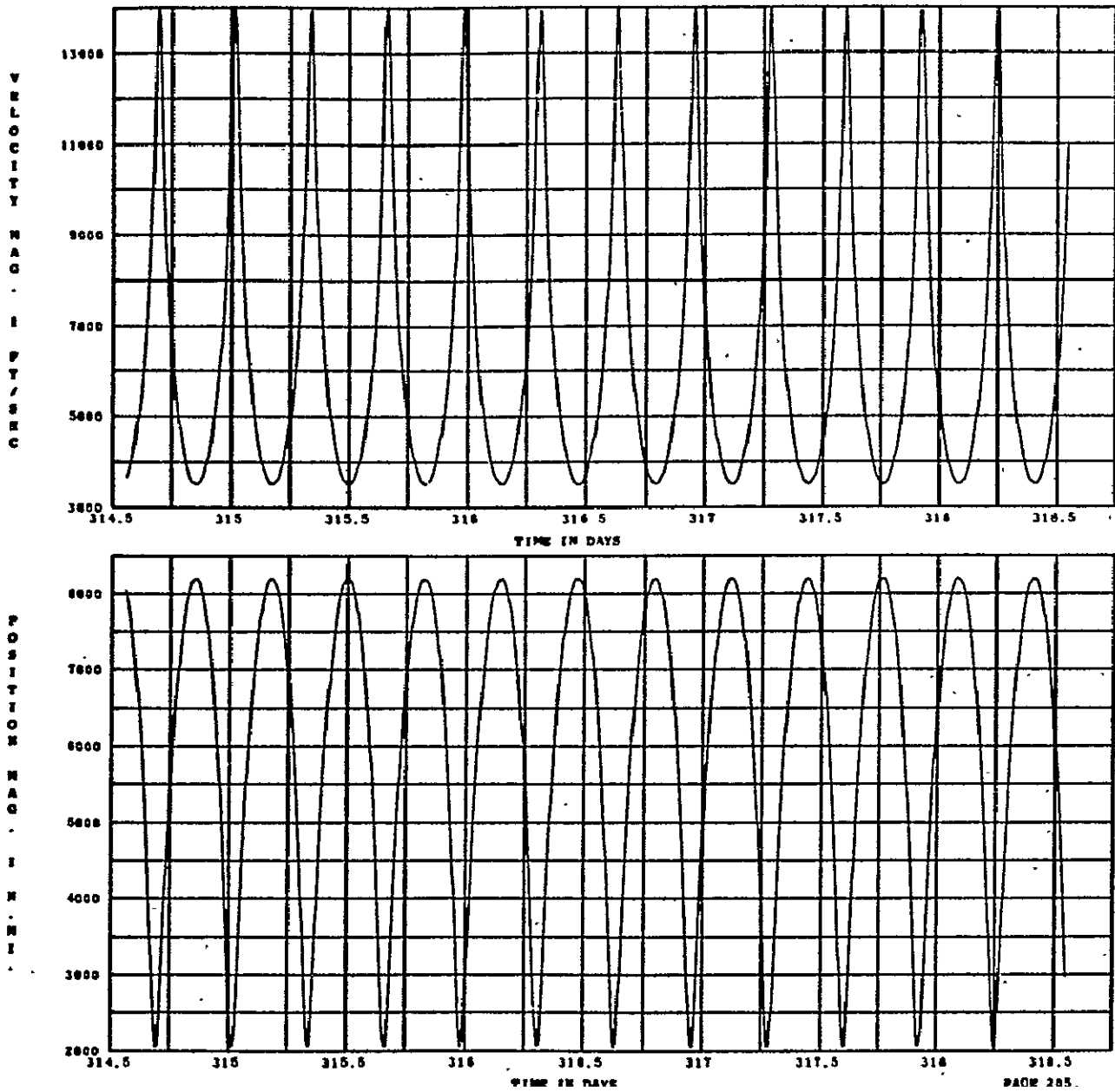
(f) Time histories of the magnitudes of the position and velocity vectors.

Figure 14.- Continued.



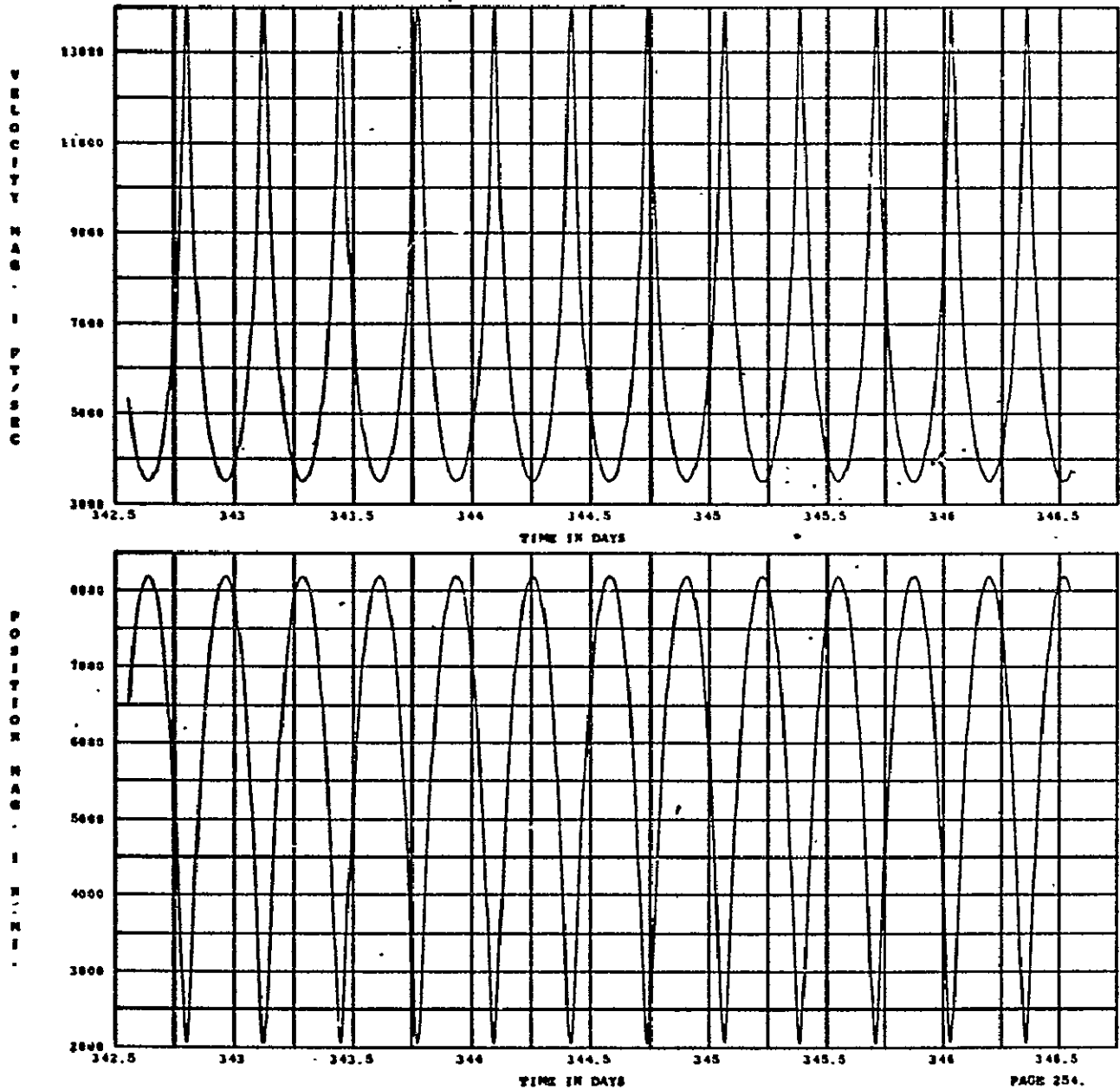
(f) Time histories of the magnitudes of the position and velocity vectors  
- continued.

Figure 14.- Continued.



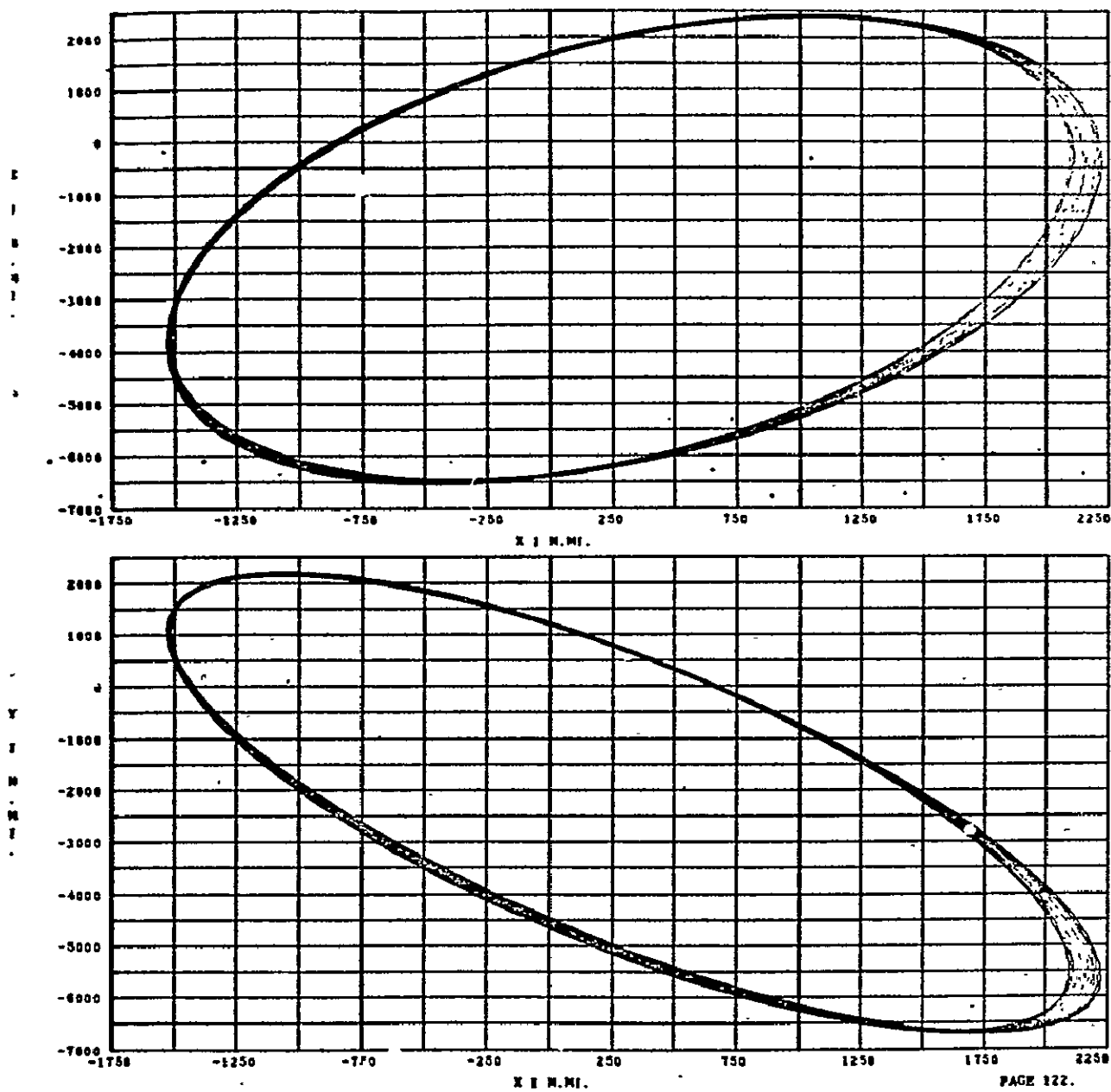
(f) Time histories of the magnitudes of the position and velocity vectors  
- continued.

Figure 14.- Continued.



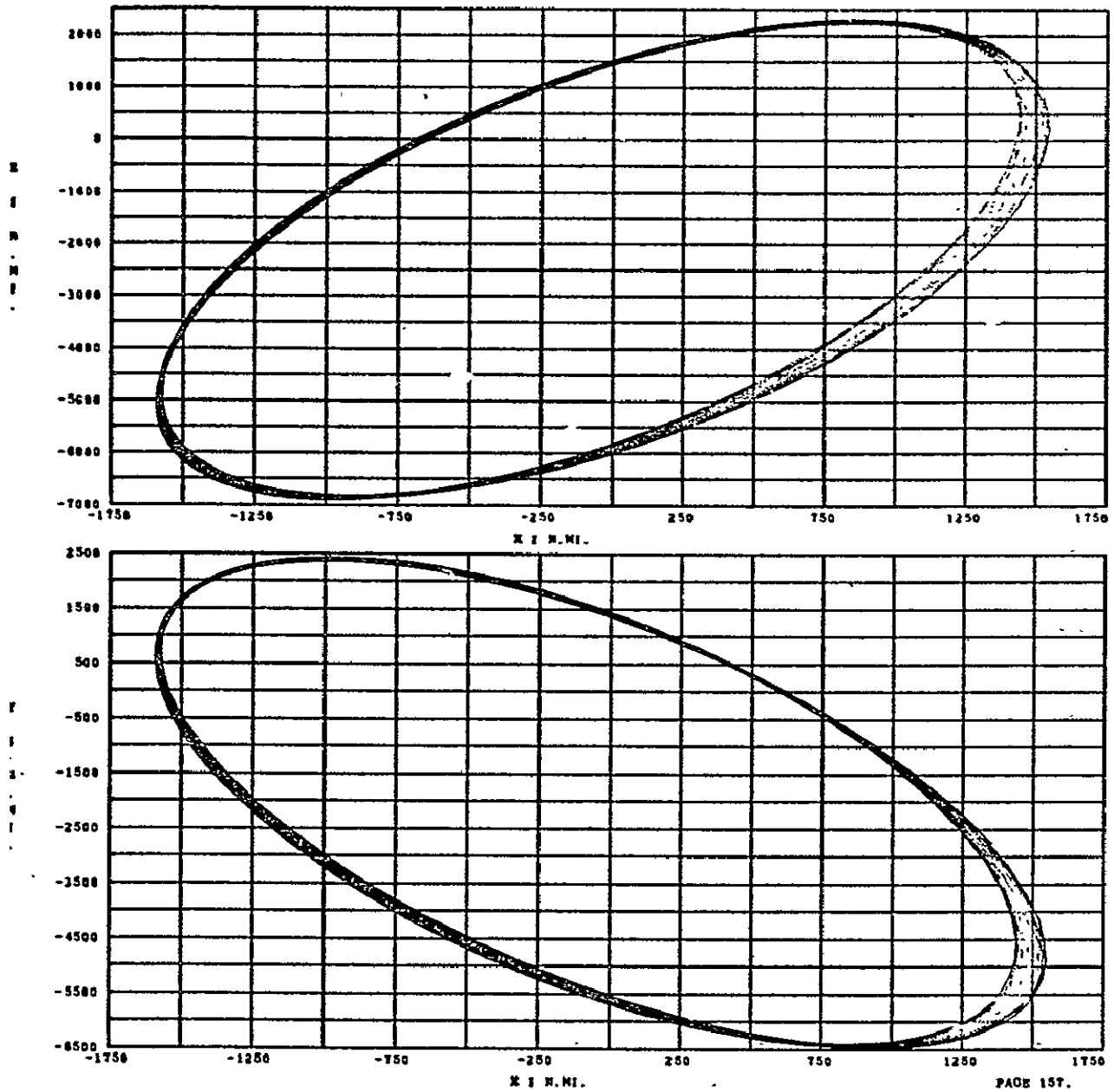
(f) Time histories of the magnitudes of the position and velocity vectors  
- concluded.

Figure 14.- Continued.



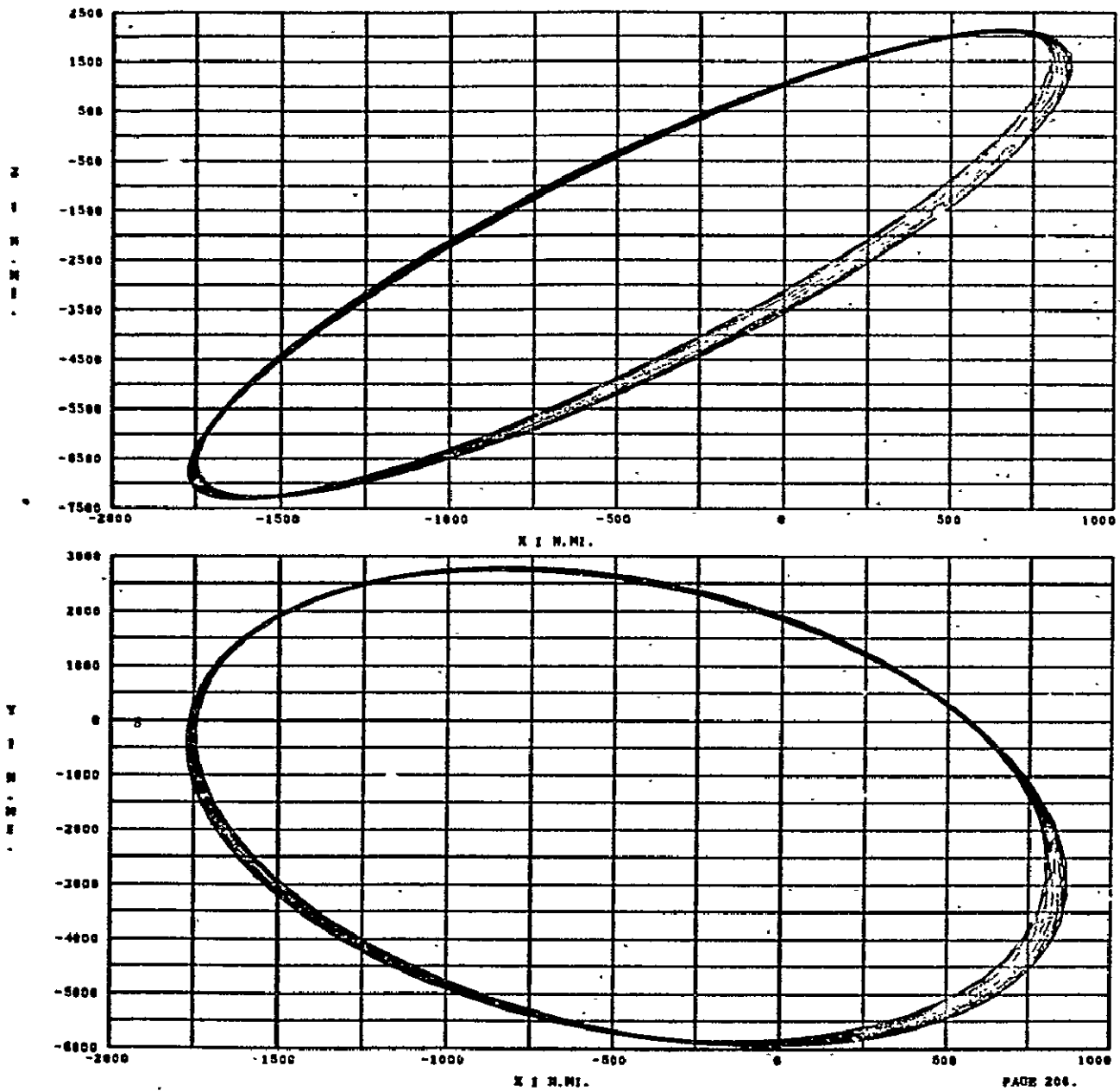
(g) Trajectory projections on the X-Y and X-Z planes.

Figure 14.- Continued.



(g) Trajectory projections on the X-Y and X-Z planes - continued.

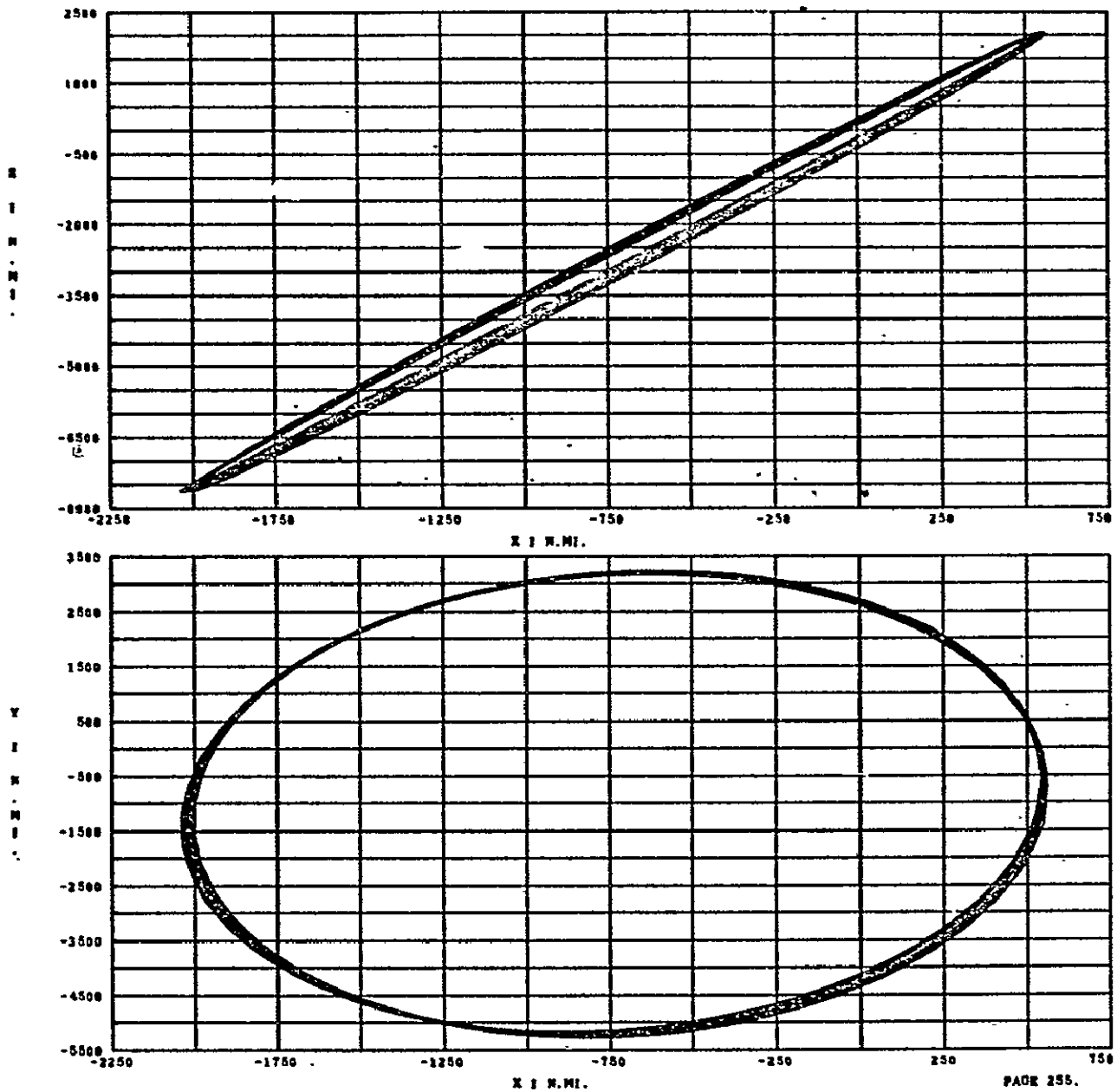
Figure 14.- Continued.



(g) Trajectory projections on the X-Y and X-Z planes - continued.

Figure 14.- Continued.





(g) Trajectory projections on the X-Y and X-Z planes - concluded.

Figure 14.- Concluded.

## 6.6 Mars Landing

The descent for the Mars landing is initiated 20.1614 days after Mars orbit insertion. The lander and main spacecraft separate, and the lander performs a 128-fps  $\Delta V$  maneuver at apoapsis of the parking orbit. This velocity change lowers the periapsis altitude of the lander's orbit to 19.8 n. mi. The first aerobraking phase begins near periapsis (3.7283 hr after descent initiation), and the descent guidance (ref. 12) attempts to steer the lander into a trajectory which has a maximum altitude of 200 n. mi. This altitude is high enough that error in the skip trajectory do not endanger the operation of the vehicle. The Mars atmospheric density profile presented in figure 15 was used in all calculations concerned with aerobraking. A time history of the acceleration and dynamic pressure during the first aerobraking phase is shown in figure 16. The maximum dynamic pressure is 52.3 psf, and the maximum acceleration is 19.2 ft/sec<sup>2</sup> (0.596 times the gravitational acceleration at the surface of the Earth). A time history of the roll angle, flight-path angle, altitude, and relative velocity is given in figures 17 and 18. The total time of the aerobraking maneuver is 320 seconds, and the velocity of the lander is reduced by approximately 3100 fps.

After the aerobraking maneuver, the apoapsis altitude of the orbit is 169.178 n. mi., and the inclination is 72.3° (decreased from 75°). At a time of 4.4722 hours after descent initiation, the lander reaches apoapsis and performs a thrusting maneuver of 298.3 fps to achieve an orbit of 169 by 180 n. mi. A thrusting maneuver of 14.9 fps is made 0.9167 hour later to establish a 180-n. mi. circular orbit. The altitude of this phasing orbit was selected as a compromise between the requirements to reach the landing site (located at 69°N latitude and 130°E longitude) and to maintain communication with the main spacecraft at the time of landing. The lander remains in this orbit until 18.2833 hours after descent initiation (approximately seven revolutions around Mars). At this time, a thrusting maneuver of 280 fps transfers the lander to the final descent trajectory. The  $\Delta V$  is not directed opposite to the motion but rather is in a direction which will minimize any error in the location of the entry point. This  $\Delta V$  direction is approximately 20° below the horizontal and is in a retro-grade direction. The final aerobraking maneuver (ref. 13) begins 18.9033 hours after descent initiation. The entry interface altitude is 158 000 feet. A time history of the acceleration and dynamic pressure during the aerobraking phase of the final descent is shown in figure 19. The maximum dynamic pressure is 70.7, psf and the maximum acceleration is 25.9 ft/sec<sup>2</sup>. A time history of the roll angle, flight-path angle, altitude, and relative velocity is shown in figures 20 and 21.

At an altitude of 36 217 feet, the propulsion braking phase of the final descent is initiated. The velocity and flight-path angle of the lander are 3451 fps and -17°, respectively. A time history of the velocity

and pitch angle is shown in figure 22, and a time history of altitude and range is shown in figure 23. The initial thrust-to-weight ratio of the vehicle is 1.5, and the specific impulse is 385 seconds. This constant thrust descent trajectory ends at an altitude of 500 feet and at a velocity of zero. The manual landing phase begins at this point. The total characteristic velocity and time required for the propulsion braking phase are 3769 fps and 67 seconds, respectively.

The effect of blackouts caused by the ionized atmosphere during entry were not considered when the communications capability between the spacecraft and lander was being determined. It is assumed that communication is possible unless the vehicles are occulted by Mars. The time periods of communication loss are indicated in figure 24 which gives a time history of the altitude and central angle between the vehicles for the entire descent phase. The two vehicles are in communication until 4.85 hours after descent initiation. This time is approximately 30 minutes prior to the circular orbit phasing maneuver. The longest time period of communication loss is slightly longer than 1 hour, while the shortest time period of communication capability is slightly shorter than 1 hour. The two vehicles have constant communication capability (except for blackouts) during the final aerobraking and propulsive braking phases and for approximately 12 minutes after the lander reaches an altitude of 500 feet. When the lander is on the surface, periods of communication are both short and infrequent. For example, communication is not possible for approximately 15 hours after landing. The communication period at that time is approximately 30 minutes, followed by a communication loss period of approximately 8 hours.

A time history of the heating rates during the first and second aerobraking phases of this descent to the Martian surface is given in figures 25 and 26, respectively. This heating rate corresponds to the stagnation point heating rate of a 1-foot radius sphere. The maximum heating rate during the aerobraking to intermediate orbit phase is 12.3 Btu/ft<sup>2</sup>-sec, while the maximum heating rate during the final braking phase is 50.6 Btu/ft<sup>2</sup>-sec. No attempt was made to determine the heating rate during the propulsive braking phase.

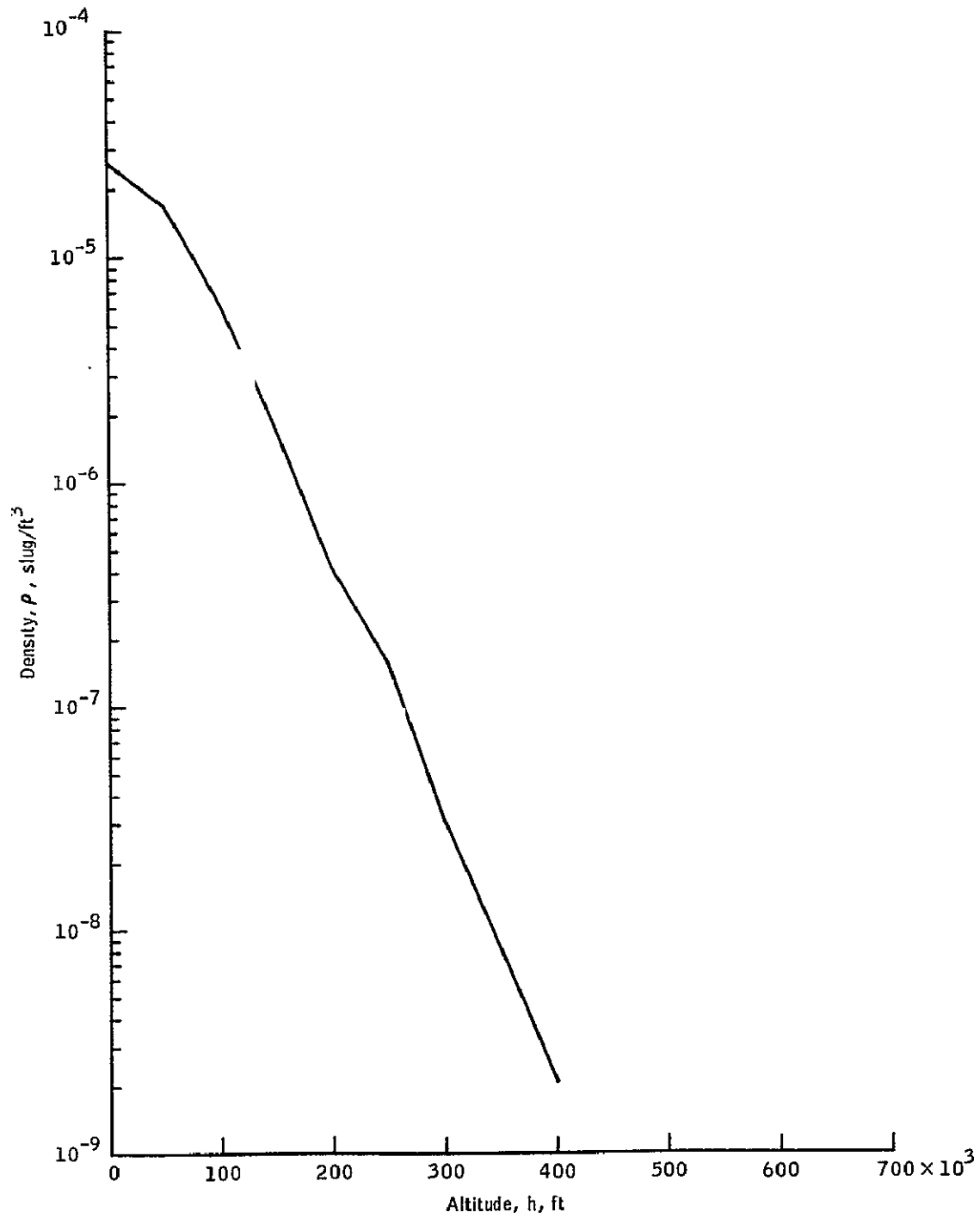


Figure 15.- Mars atmospheric density profile.

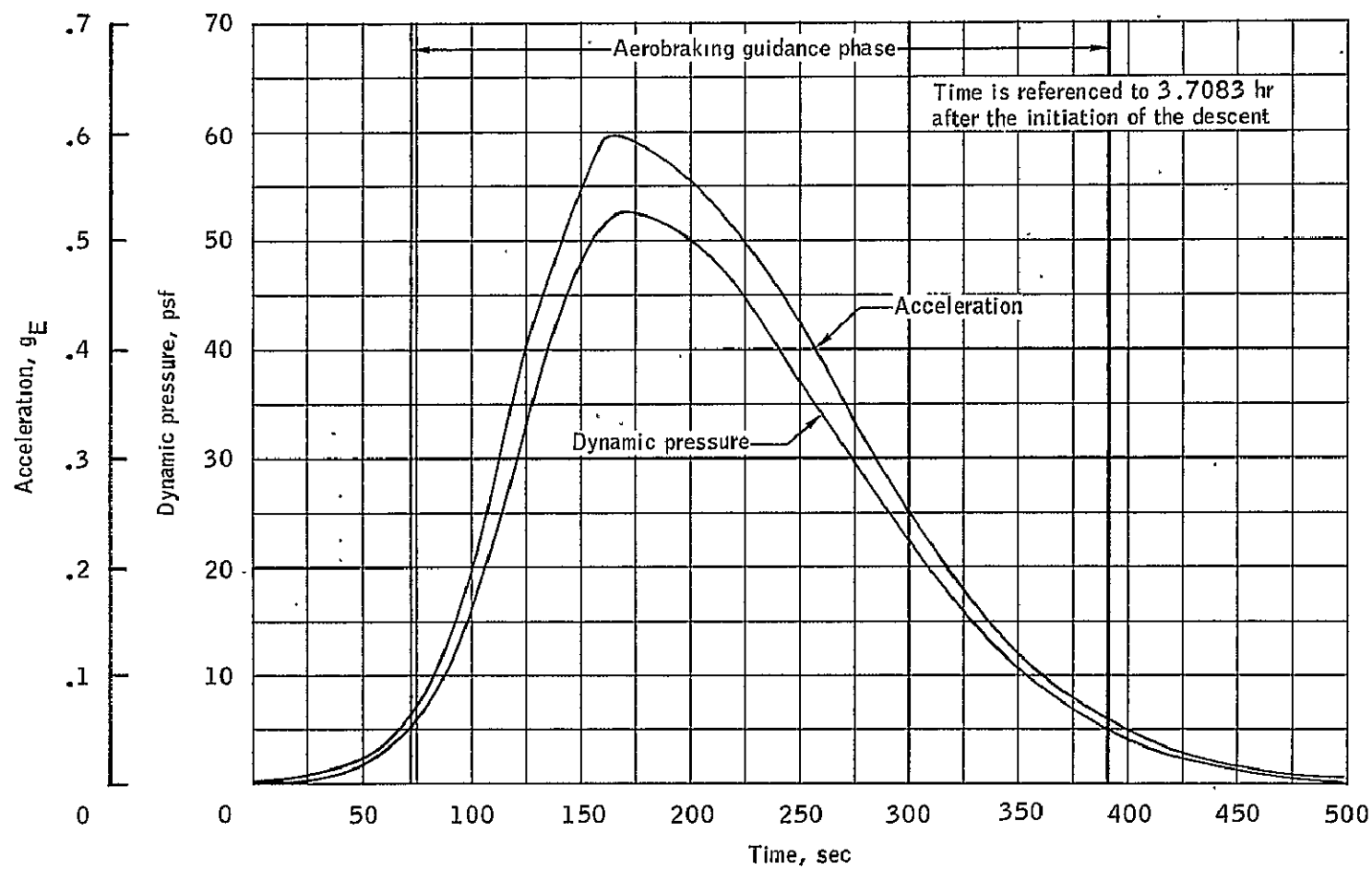


Figure 16.- Time history of acceleration and dynamic pressure during aerobraking to intermediate orbit around Mars.

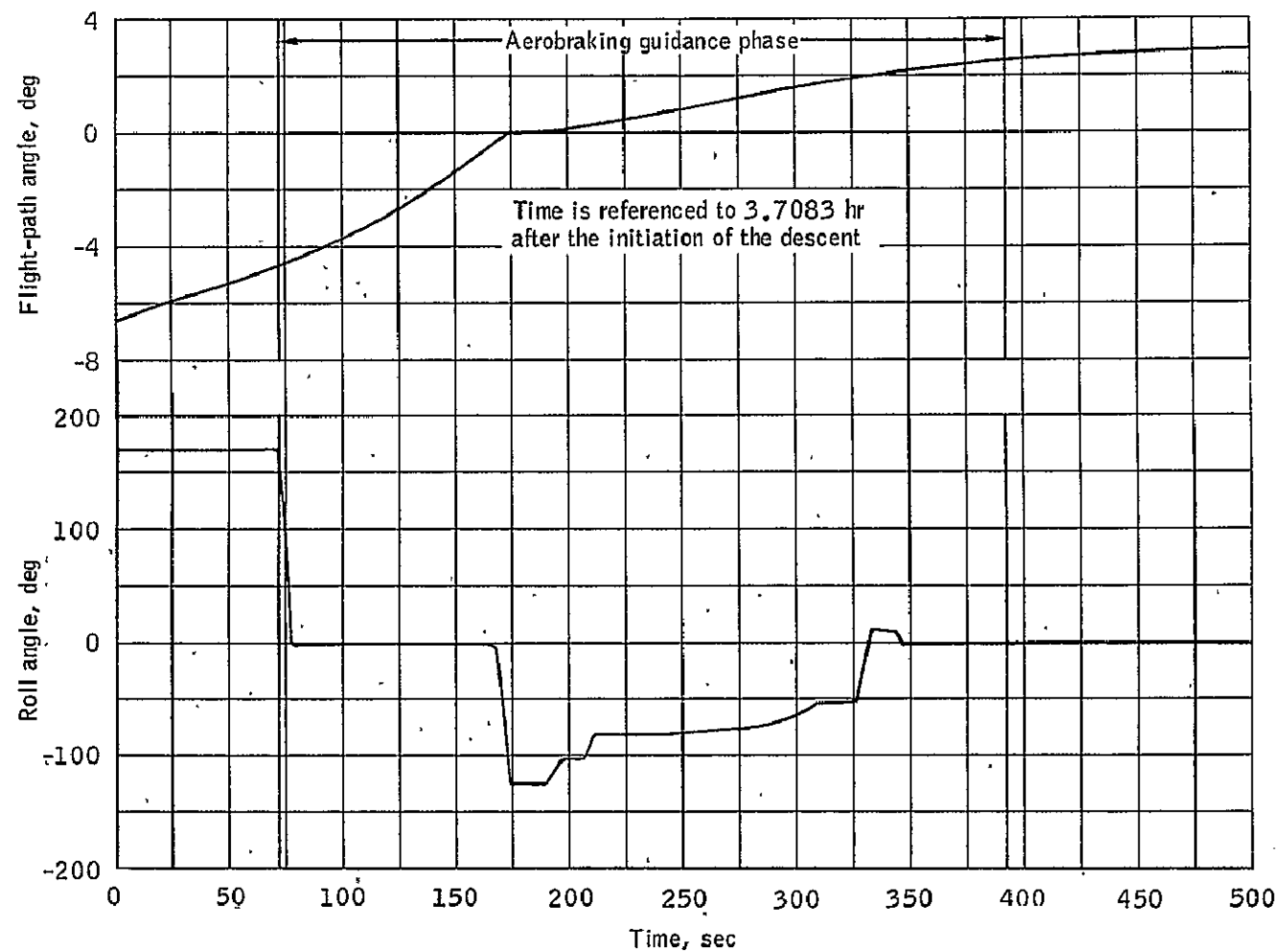


Figure 17.- Time history of roll angle and flight-path angle during aerobraking to intermediate orbit around Mars.

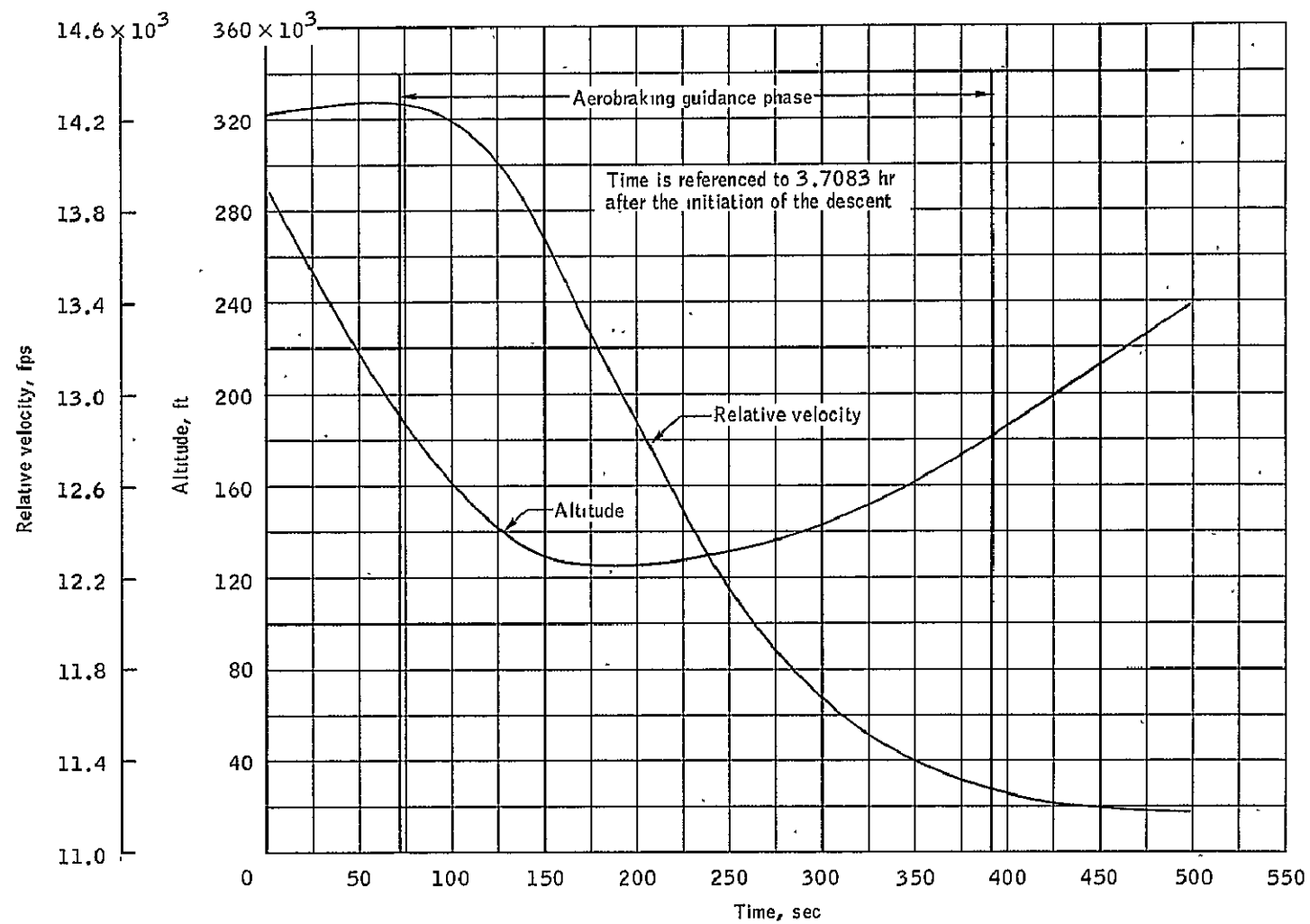


Figure 18.- Time history of altitude and relative velocity during aerobraking to intermediate orbit around Mars.

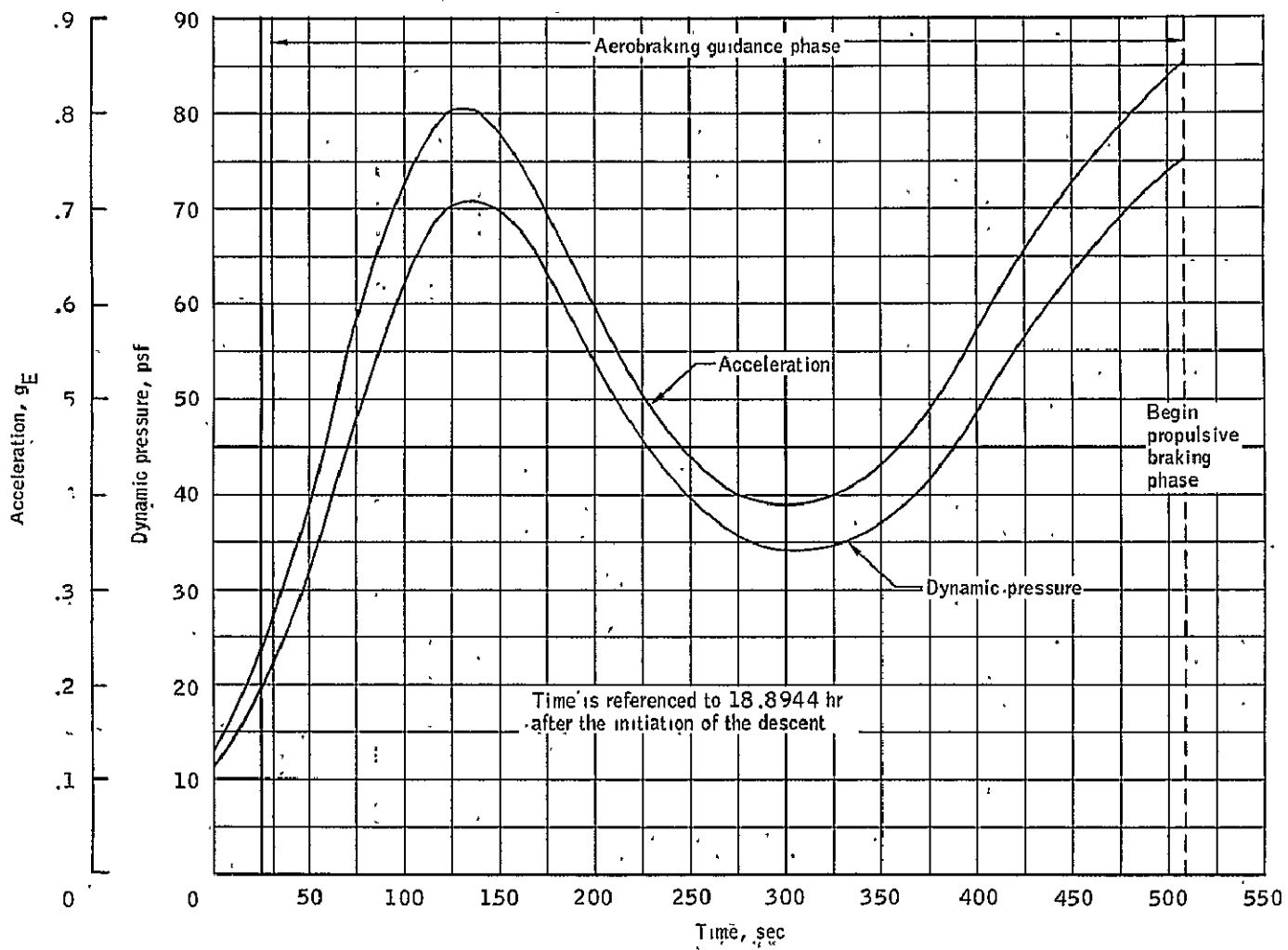


Figure 19.- Time history of acceleration and dynamic pressure during final descent to Mars surface.



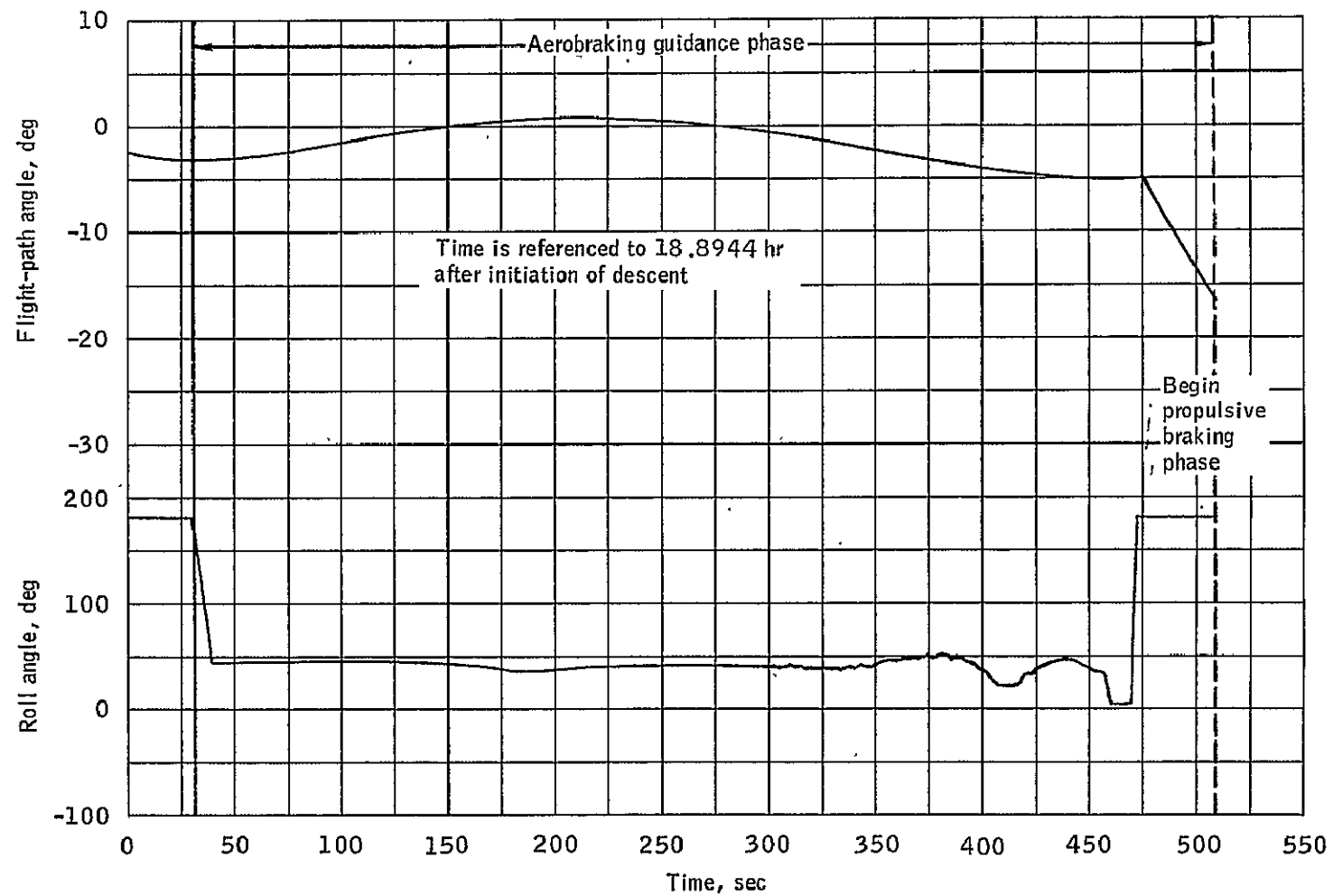


Figure 20.- Time history of roll angle and flight-path angle during final descent to Mars surface.

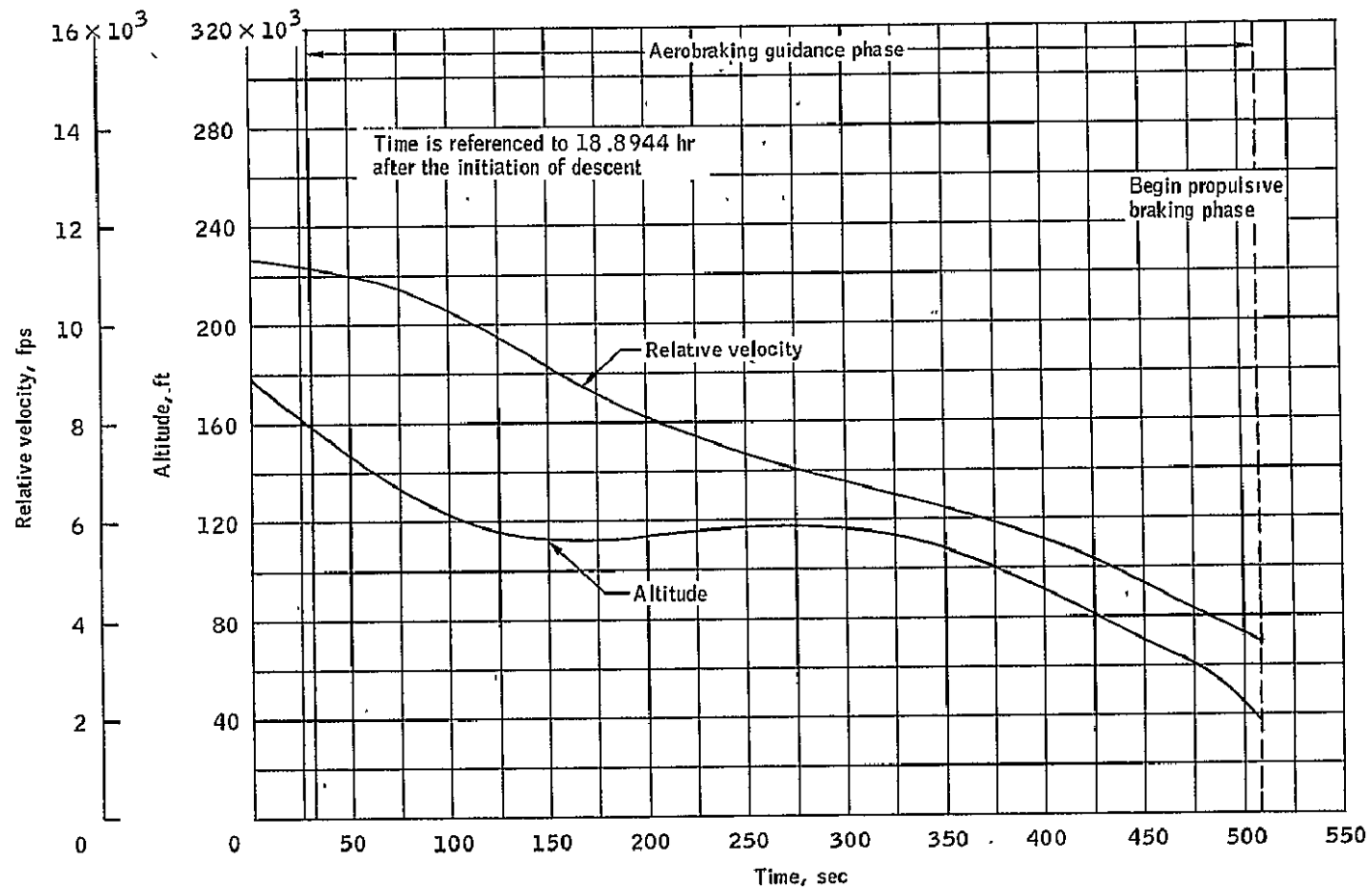


Figure 21.- Time history of altitude and relative velocity during final descent to Mars surface.

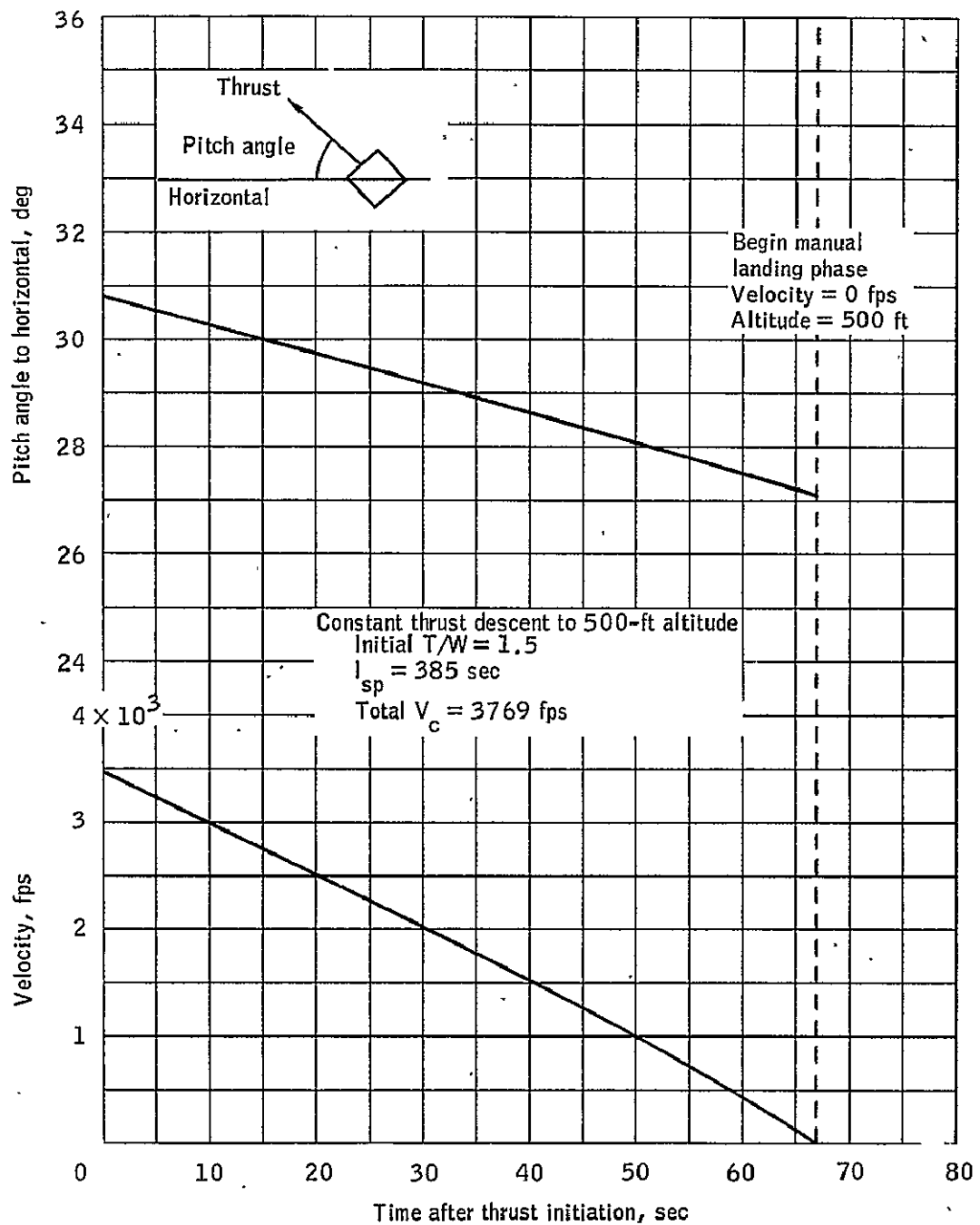


Figure 22.- Velocity and pitch angle time history for propulsive braking phase of Mars landing.

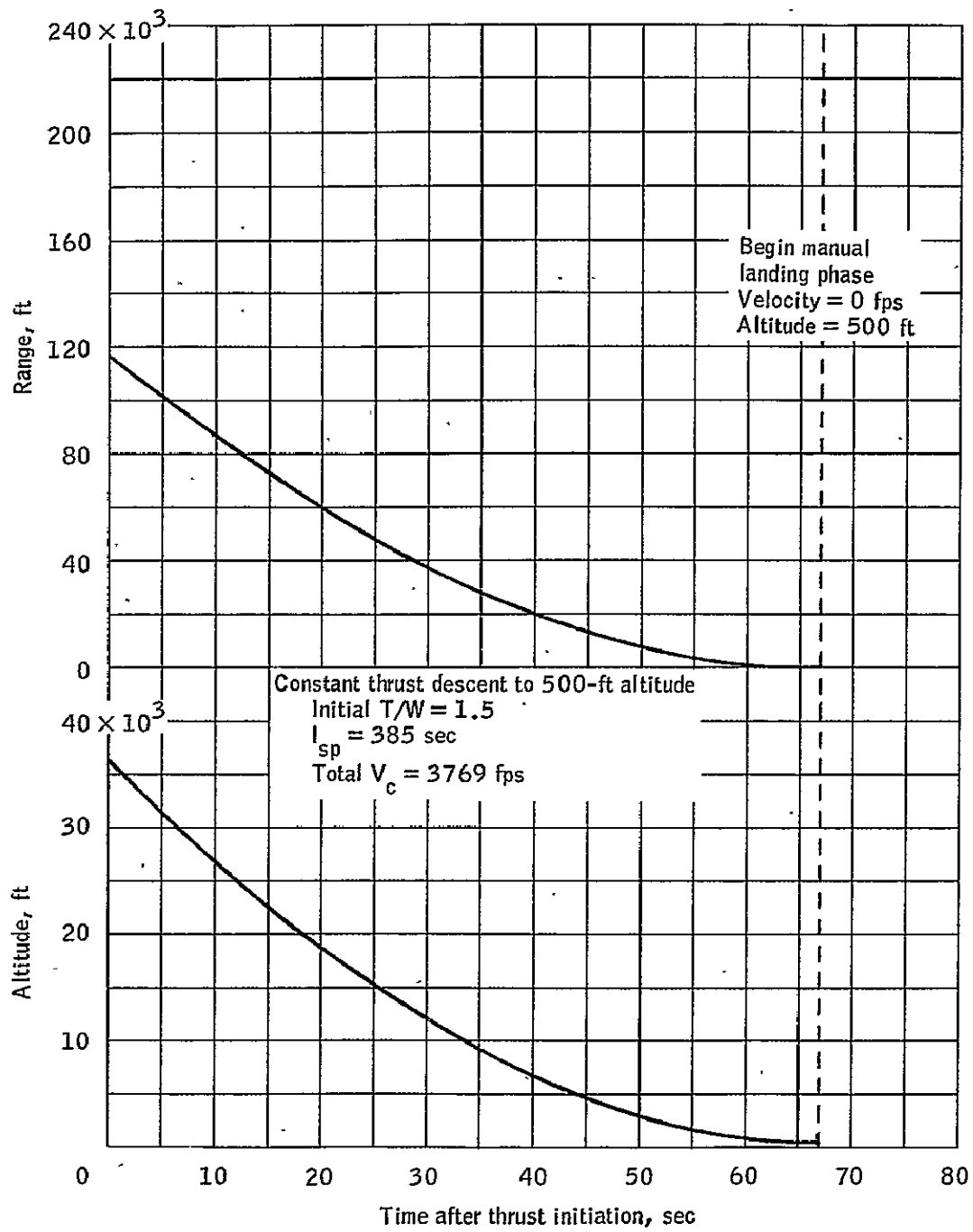


Figure 23.- Altitude and range time history for propulsive braking phase of Mars landing.

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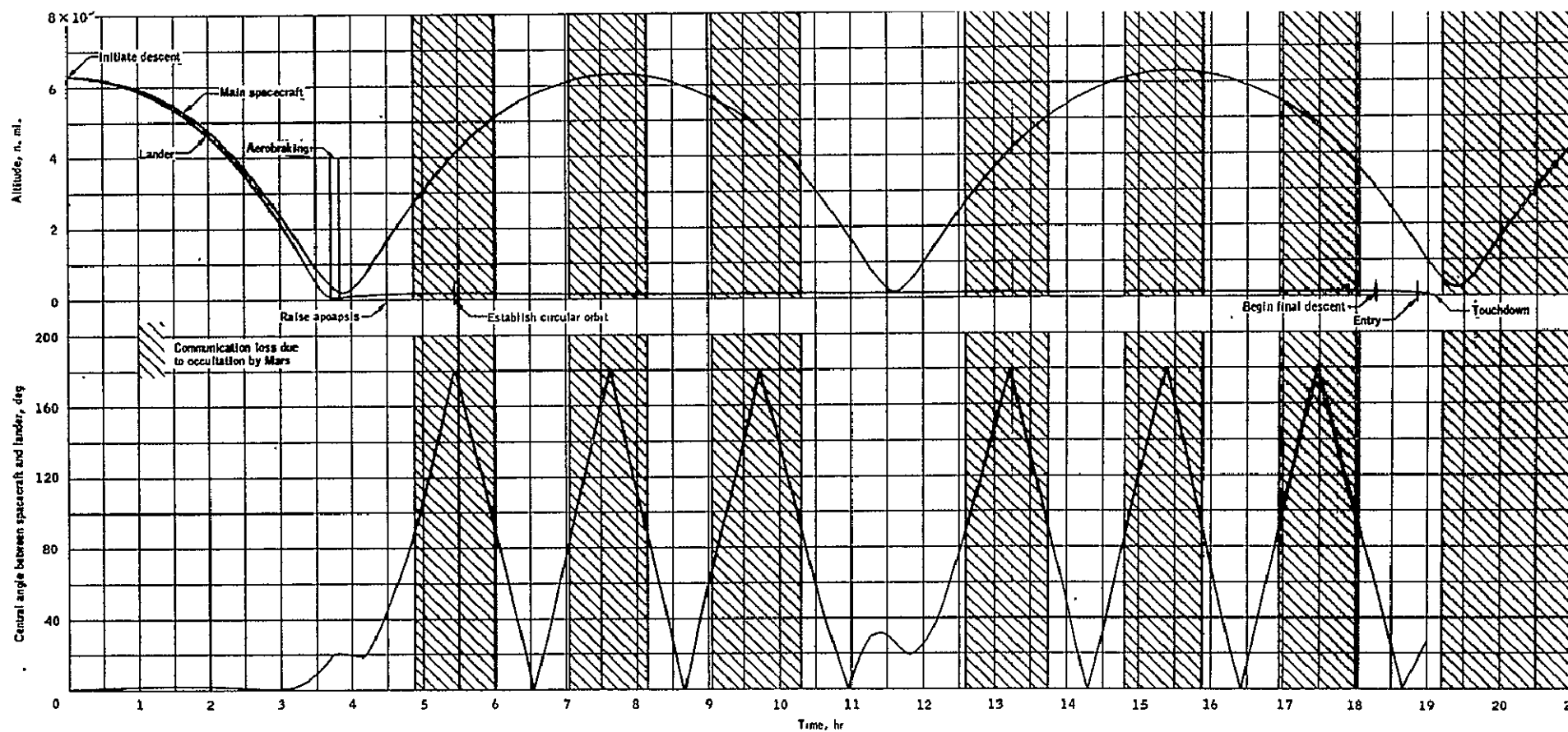


Figure 24.- Time history of altitude and central angle between spacecraft and lander during lander descent to Mars surface.

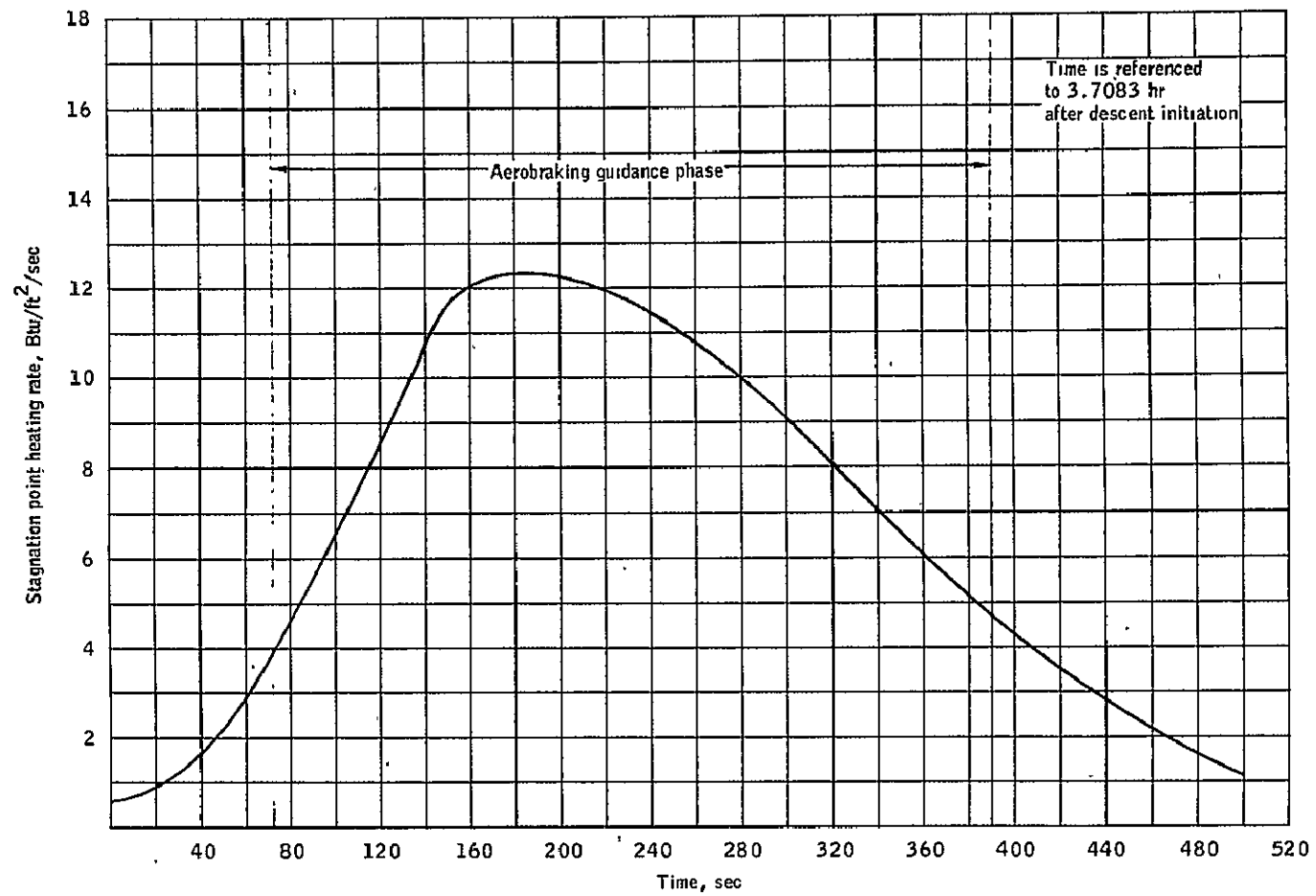


Figure 25.- Time history of stagnation point heating rate of 1-foot radius sphere during aerobraking to intermediate orbit around Mars.

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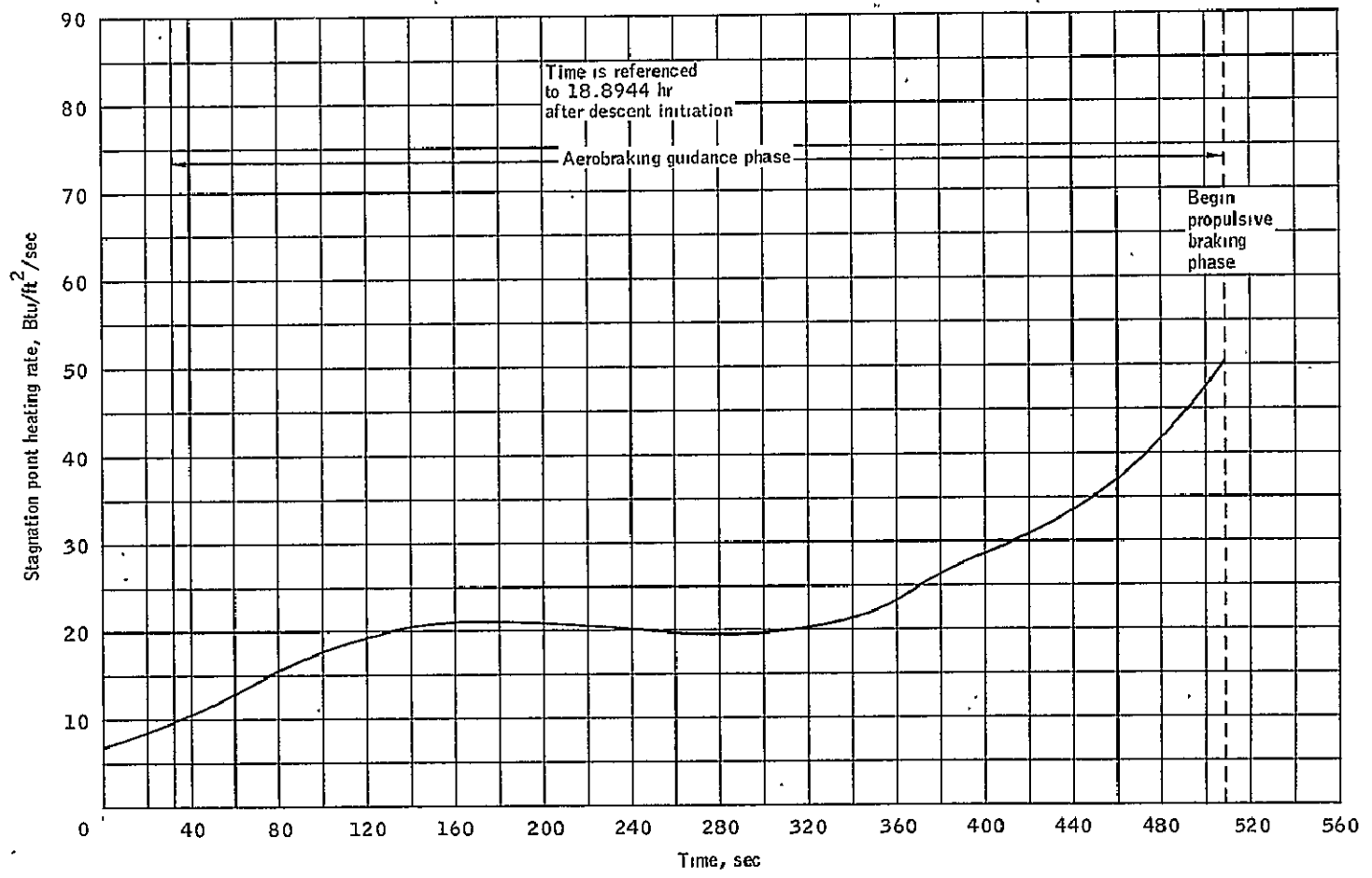


Figure 26.- Time history of stagnation point heating rate of 1-foot radius sphere during final descent to Mars surface.

## 6.7 Mars Launch and Rendezvous

Mars lander ascent and rendezvous is initiated after a nominal staytime of 30 days. The Mars atmospheric density profile used for all calculations of flight in the Martian atmosphere is shown in figure 15 (section 8.6). The specific impulse of the stage is 380 seconds, and the ballistic parameter ( $W_0/C_D A$ ) is 400 lb/ft<sup>2</sup>. The characteristic velocity required for a time optimum launch from an altitude of 100 feet and a vertical velocity of 60 fps to a 300 000- to 400 000-foot by 100-n. mi. Mars orbit is shown in figure 27 as a function of thrust-to-weight ratio for a true anomaly at orbit insertion of 5°. Studies indicated that the characteristic velocity requirement is insensitive to variations in true anomaly at orbit insertion between ±10° (ref. 14). The 300 000-foot by 100-n. mi. orbit was chosen for further study because it had the lowest velocity requirement. Orbits with lower periapsis altitudes have undesirably short orbit decay times. A thrust-to-weight ratio of 1.0 was assumed for which the velocity requirement for orbit insertion is 13 620 fps. The ΔV required for the vertical rise to a 100-foot altitude and 60-fps vertical velocity is 96 fps for a total ΔV to orbit of 13 716 fps. Time histories of the radial and tangential velocities are given in figure 28, and time histories of the altitude and vehicle pitch angle to the horizontal are given in figure 29. A time history of the stagnation point heating rate of a 1-foot radius sphere during this ascent phase is given in figure 30.

The rendezvous phase between the lander and spacecraft is initiated at the time of orbit insertion of the lander ascent stage. An optimum multiple impulse technique (refs. 15 and 16) was used to simulate this lander active rendezvous. Two coplanar launches from the surface are considered; one with a northeast launch azimuth and the other with a southeast launch azimuth. The impulsive ΔV required for rendezvous after each of these launches is given in figure 31 as a function of the coast time in the initial orbit (300 000 ft by 100 n. mi.). The maximum total time allowed for rendezvous is 24 hours. The minimum ΔV of 3214 fps results after a northeast coplanar launch and a 10.88-hour coast prior to the first impulse. Time histories of the range, altitude, and phase angle are given in figures 32, 33, and 34, respectively, for the optimum northeast launch.

The MEM ascent stage passes through the Martian shadow during the rendezvous sequence. The penumbra is entered at 16 hours 14 minutes after Mars lift-off; the umbra is entered at 16 hours 17 minutes and is exited at 17 hours 25 minutes. The vehicle reenters sunlight at 17 hours 26 minutes (i.e., exit of penumbra). The rest of the nominal rendezvous sequence is in sunlight.



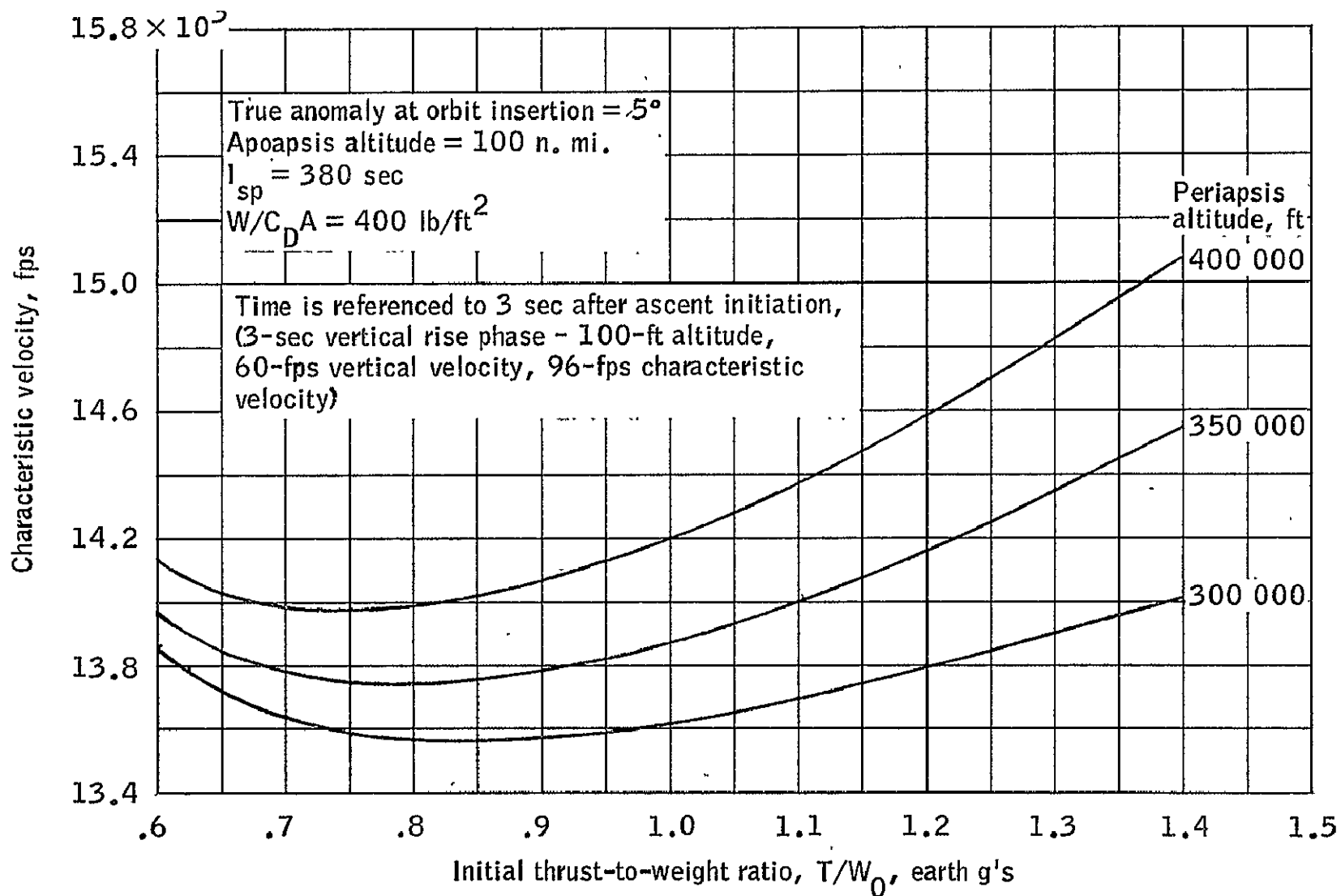


Figure 27.- Characteristic velocity required for launch to Mars orbit.

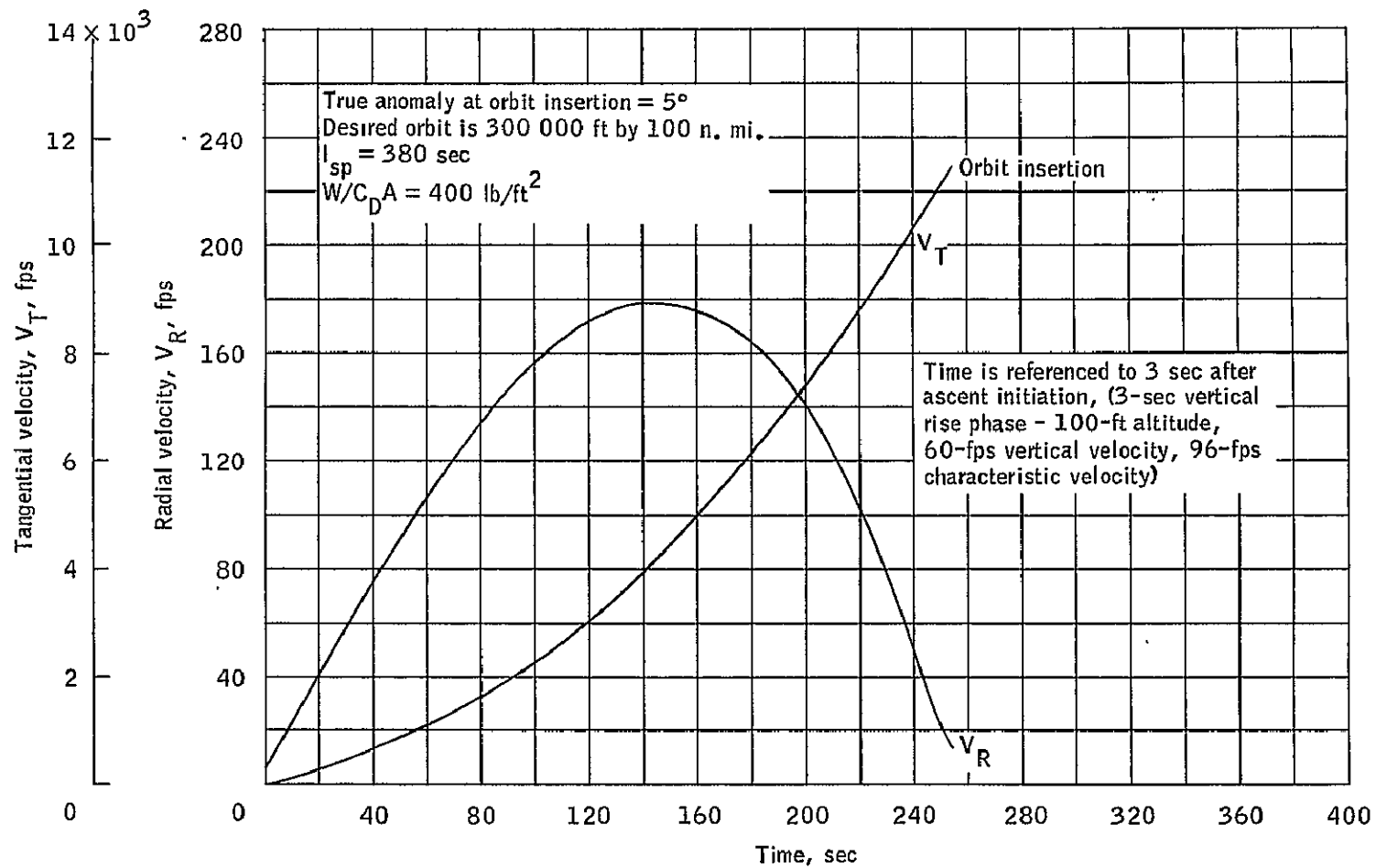


Figure 28.- Time history of radial and tangential velocities during ascent to Mars orbit.

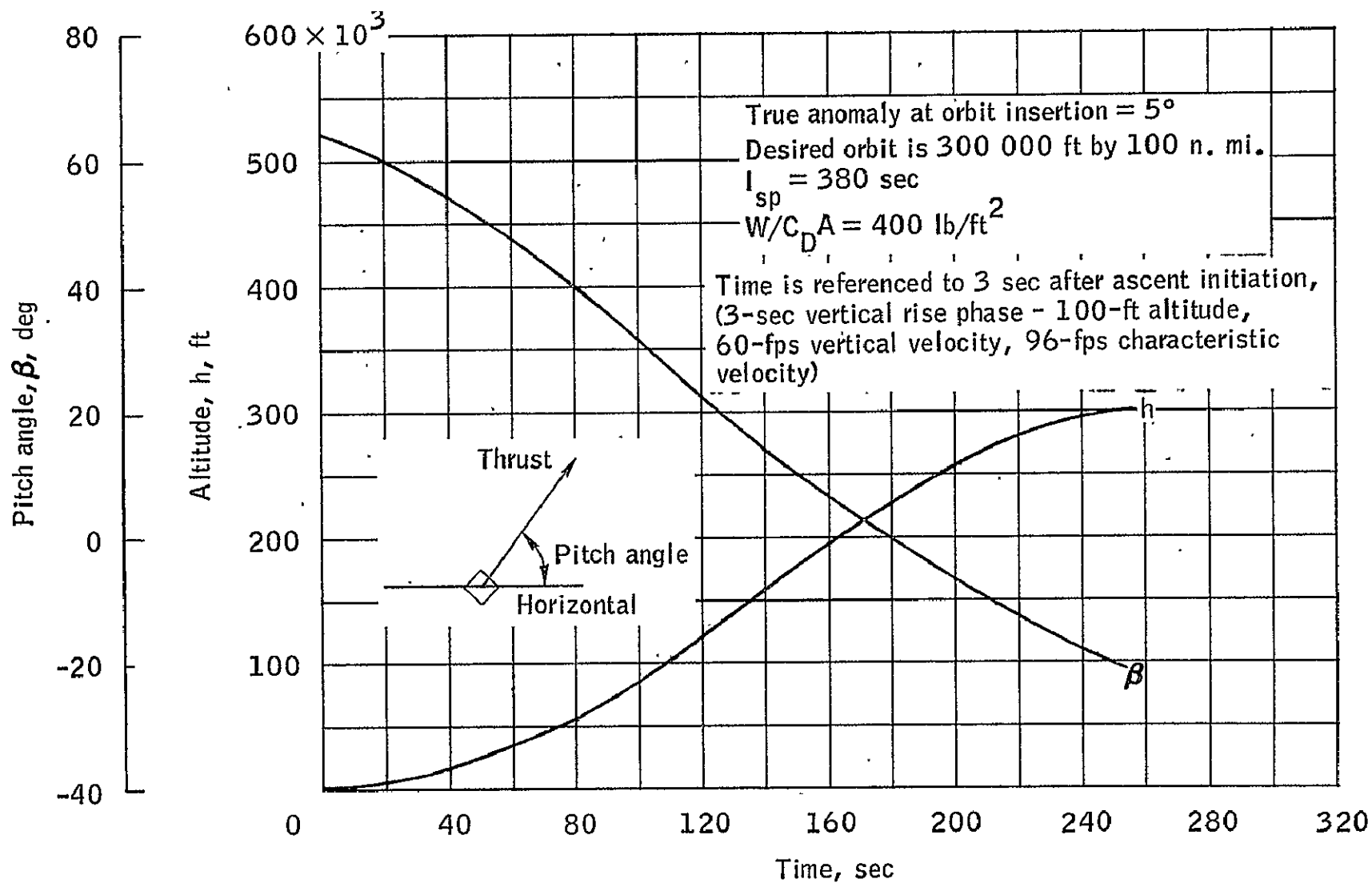


Figure 29.- Time history of altitude and pitch angle during ascent to Mars orbit.

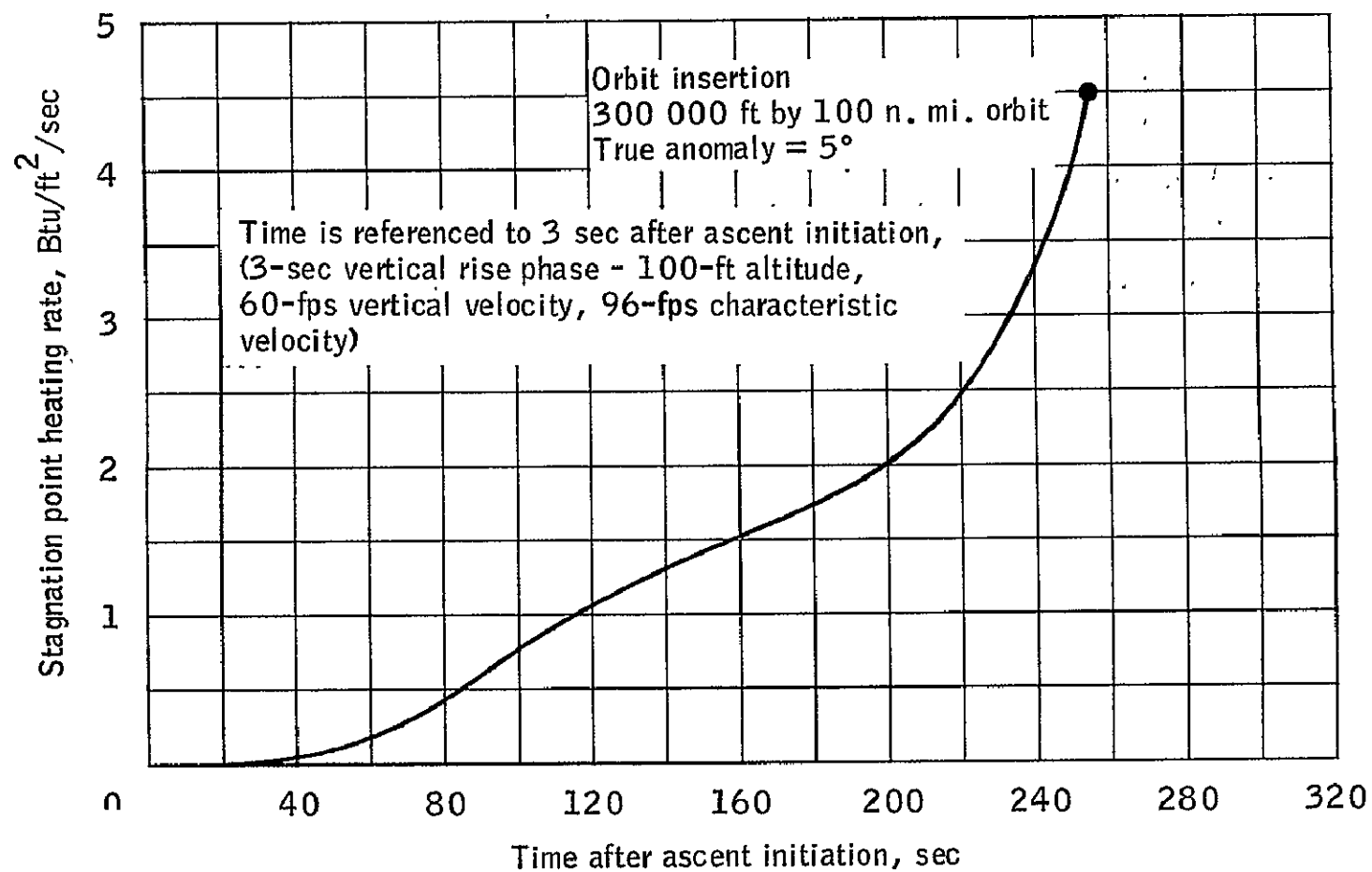
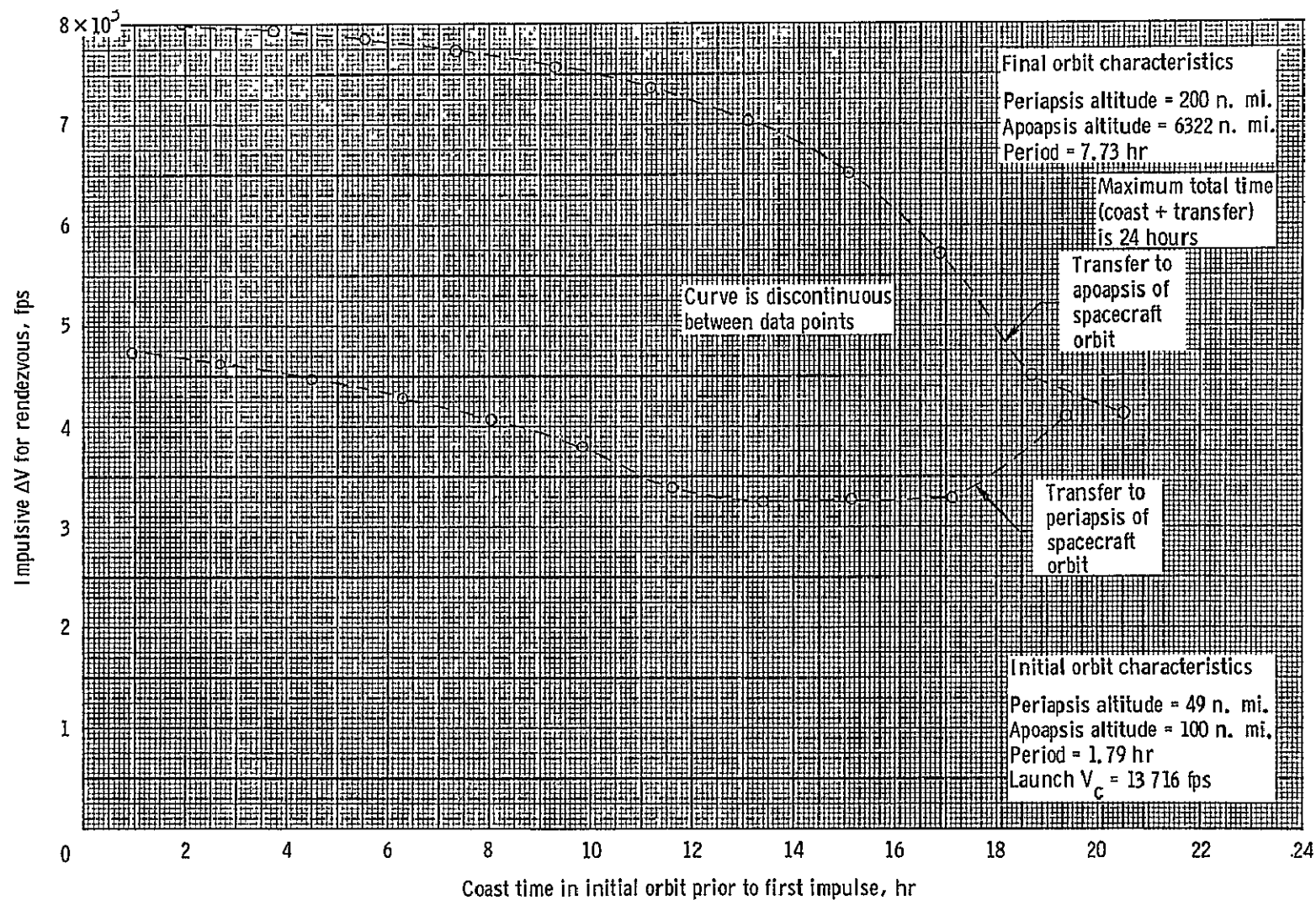
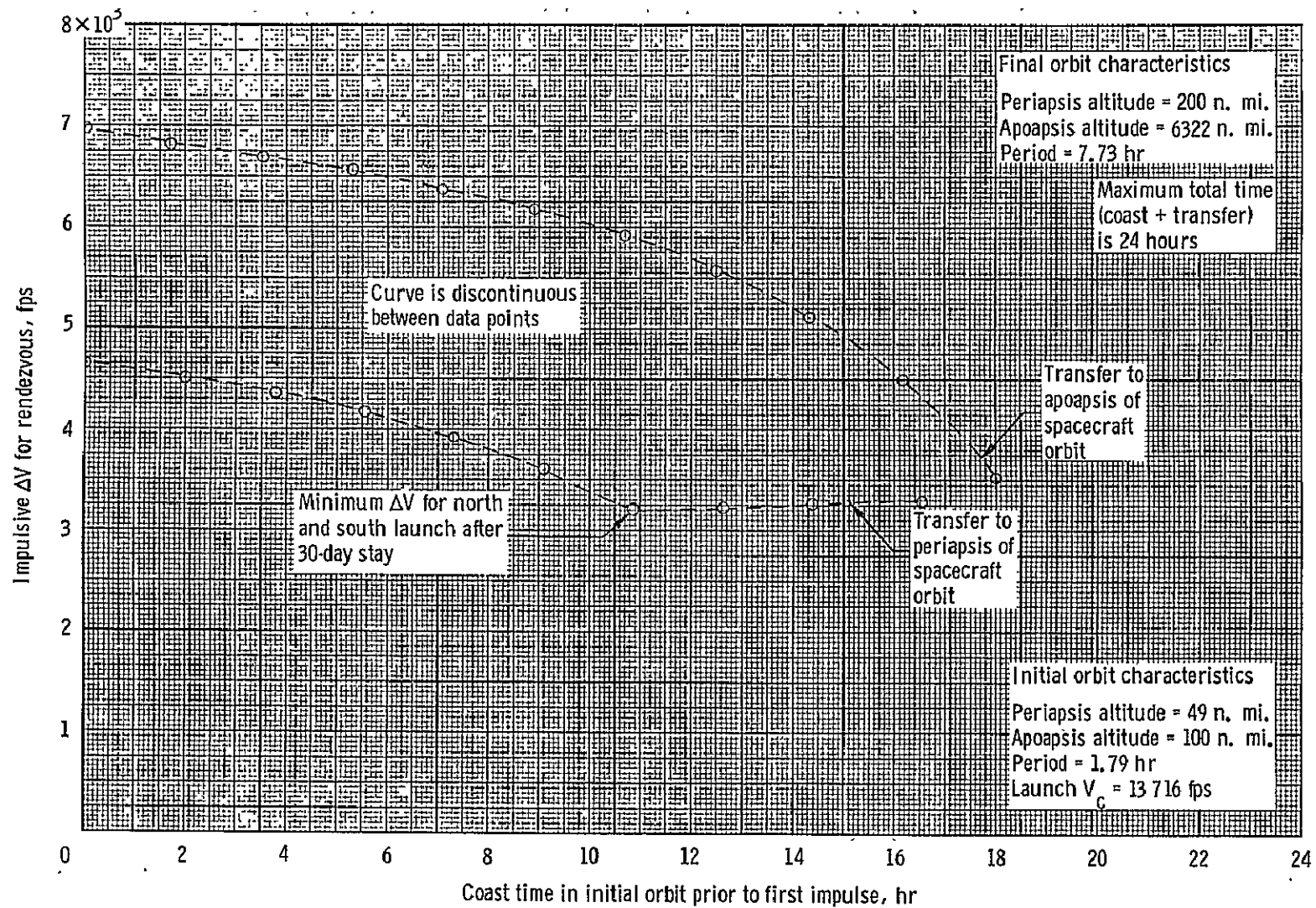


Figure 30.- Time history of stagnation point heating rate of 1-foot radius sphere during ascent from Martian surface.



(a) South coplanar launch.

Figure 31. - Mars lander rendezvous velocity requirements after nominal surface staytime (30 days).



(b) North coplanar launch.

Figure 31. - Concluded.

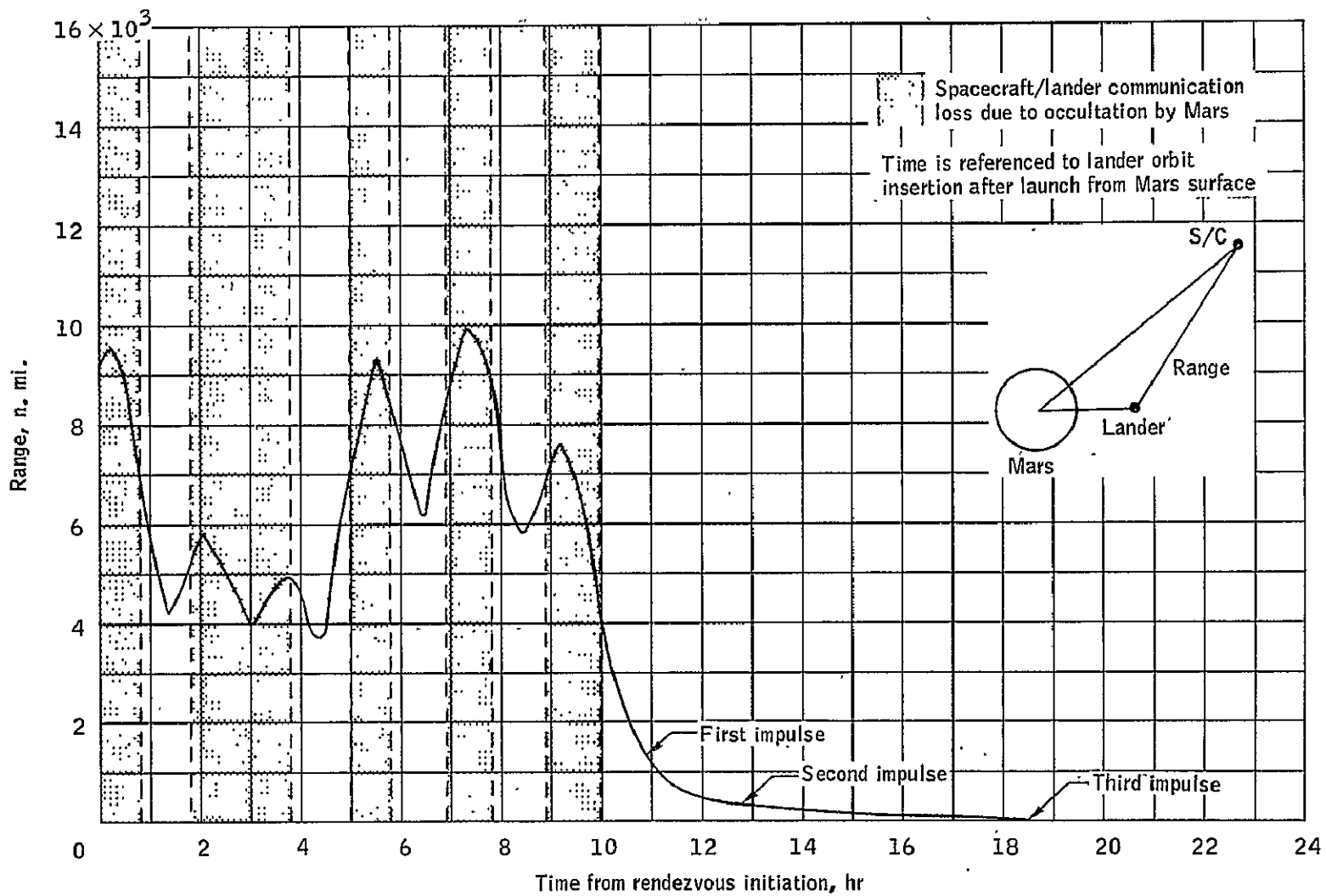


Figure 32.- Rendezvous range time history.

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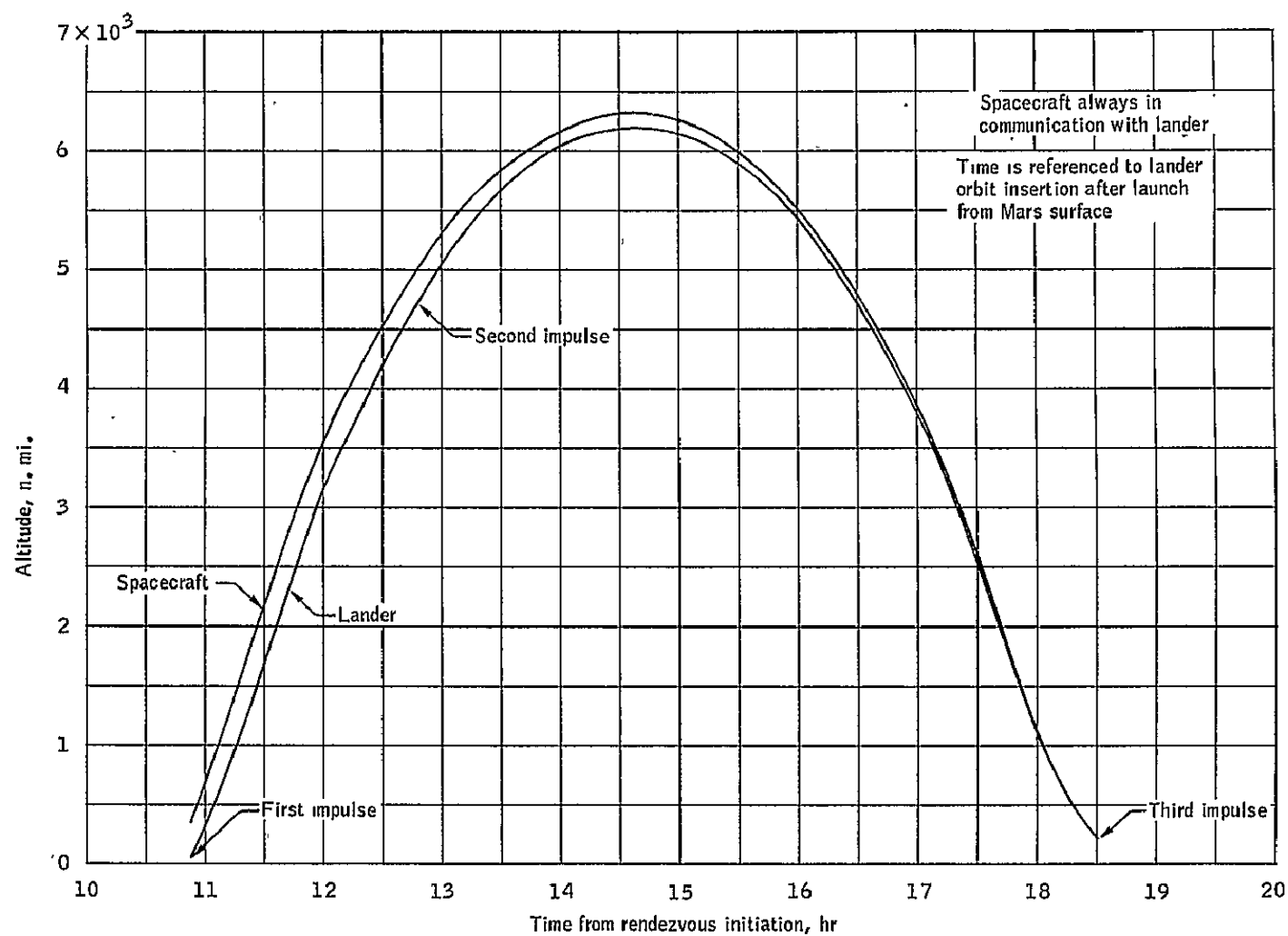


Figure 33.- Altitude time history for terminal phase of rendezvous.



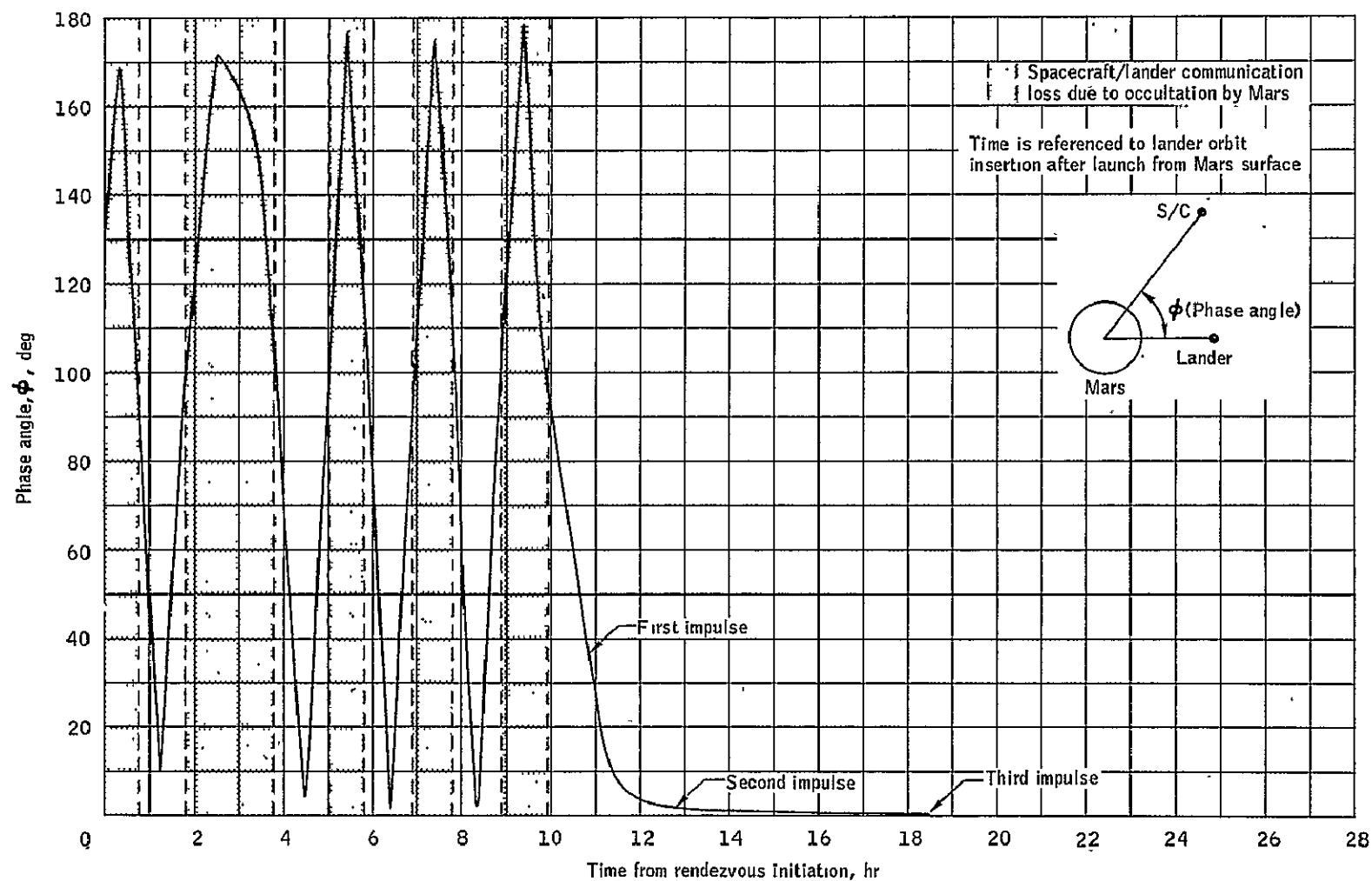
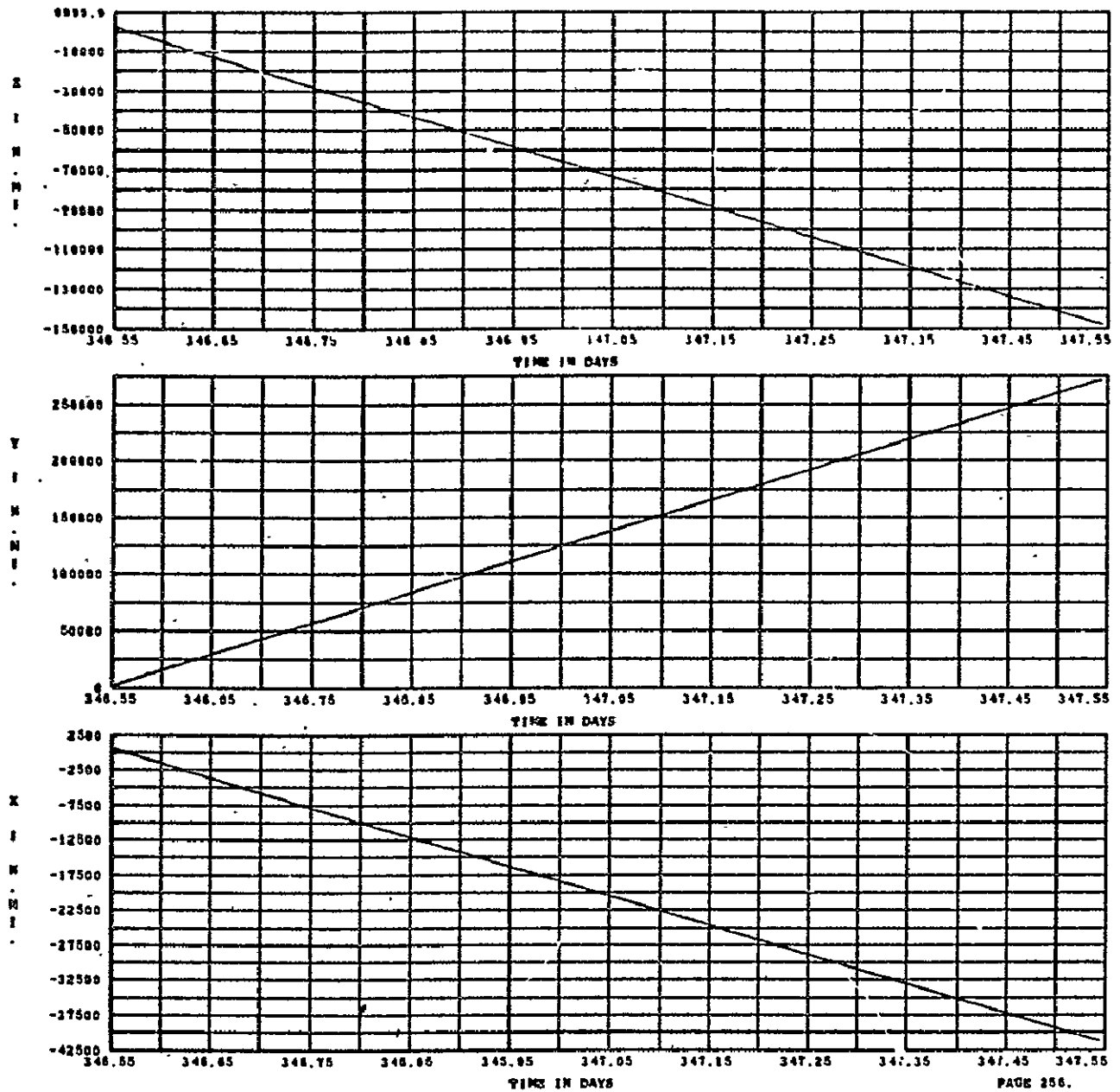


Figure 34.- Rendezvous phasing time history.

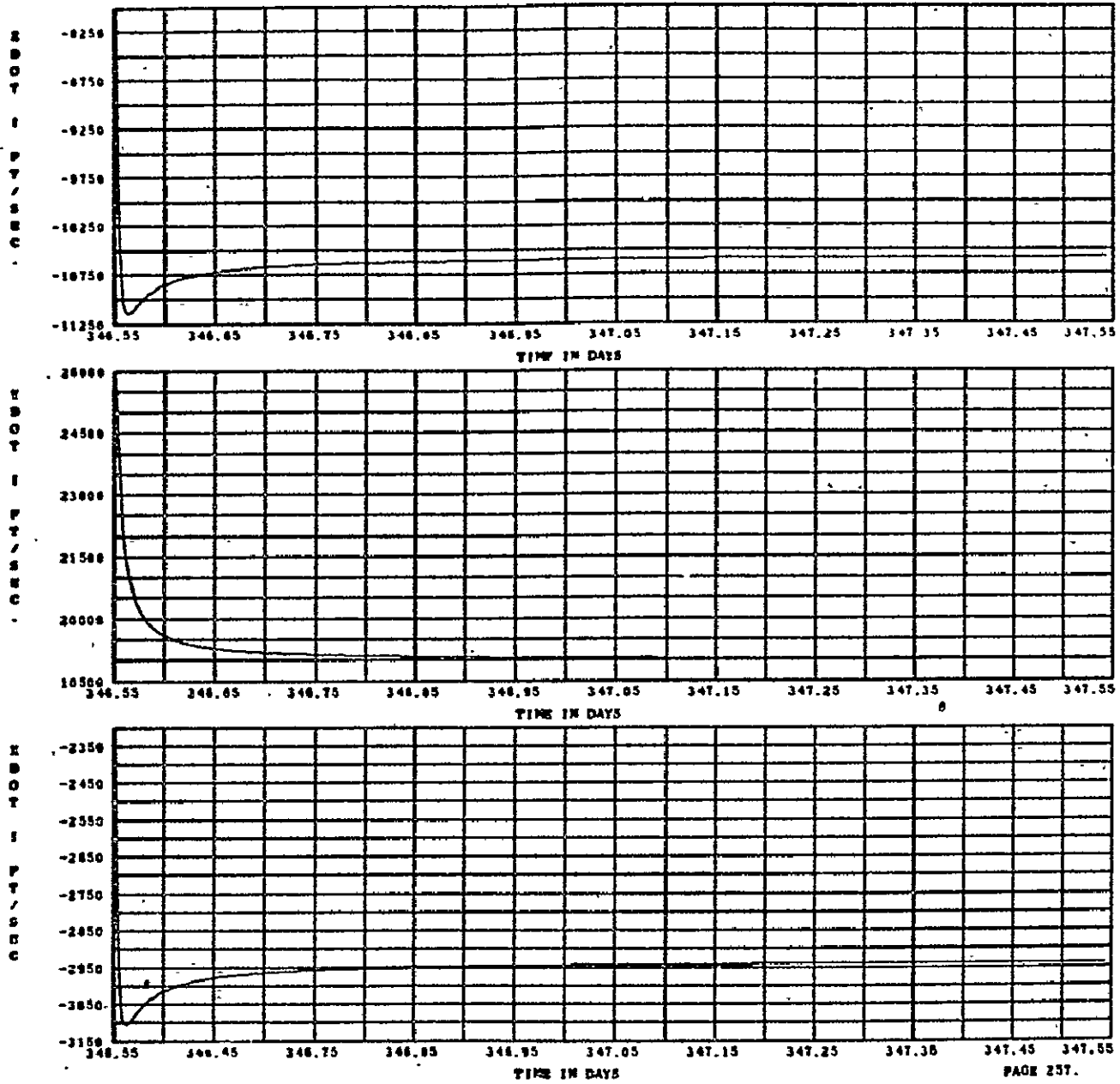
## 6.8 Transearth Injection

Periapsis of the Mars parking orbit rotates under the influence of the Mars oblate gravitational field such that after the nominal staytime of 80 days, the orbit is correctly aligned to permit a coplanar transearth injection maneuver. That maneuver is simulated by a single impulse of 12 929 fps (excluding gravity losses) and is targeted for a swingby of Venus 127 days later. A time history of the trajectory parameters of the departure hyperbola (periapsis to the Mars SOI) is shown in figure 35. The velocity at periapsis is 26 911 fps, and the velocity at the Mars SOI is 21 904 fps. The transfer angle is  $101^\circ$ , and the transfer time is 28.9 hours.



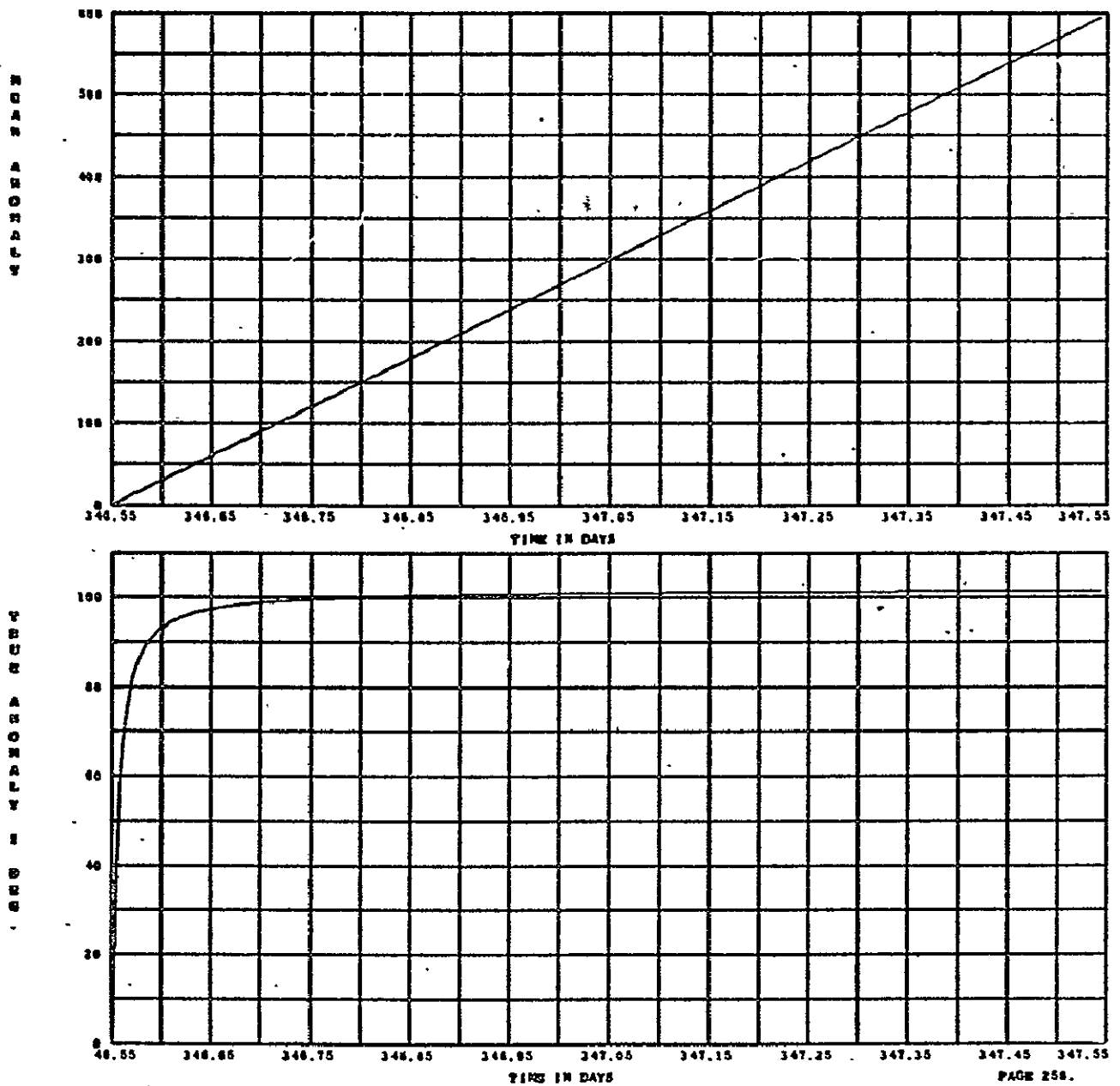
(a) Time histories of the Cartesian components of the position vector.

Figure 35.- Mars departure trajectory parameters (areocentric or mass equatorial coordinate system) periaopsis to sphere of influence.



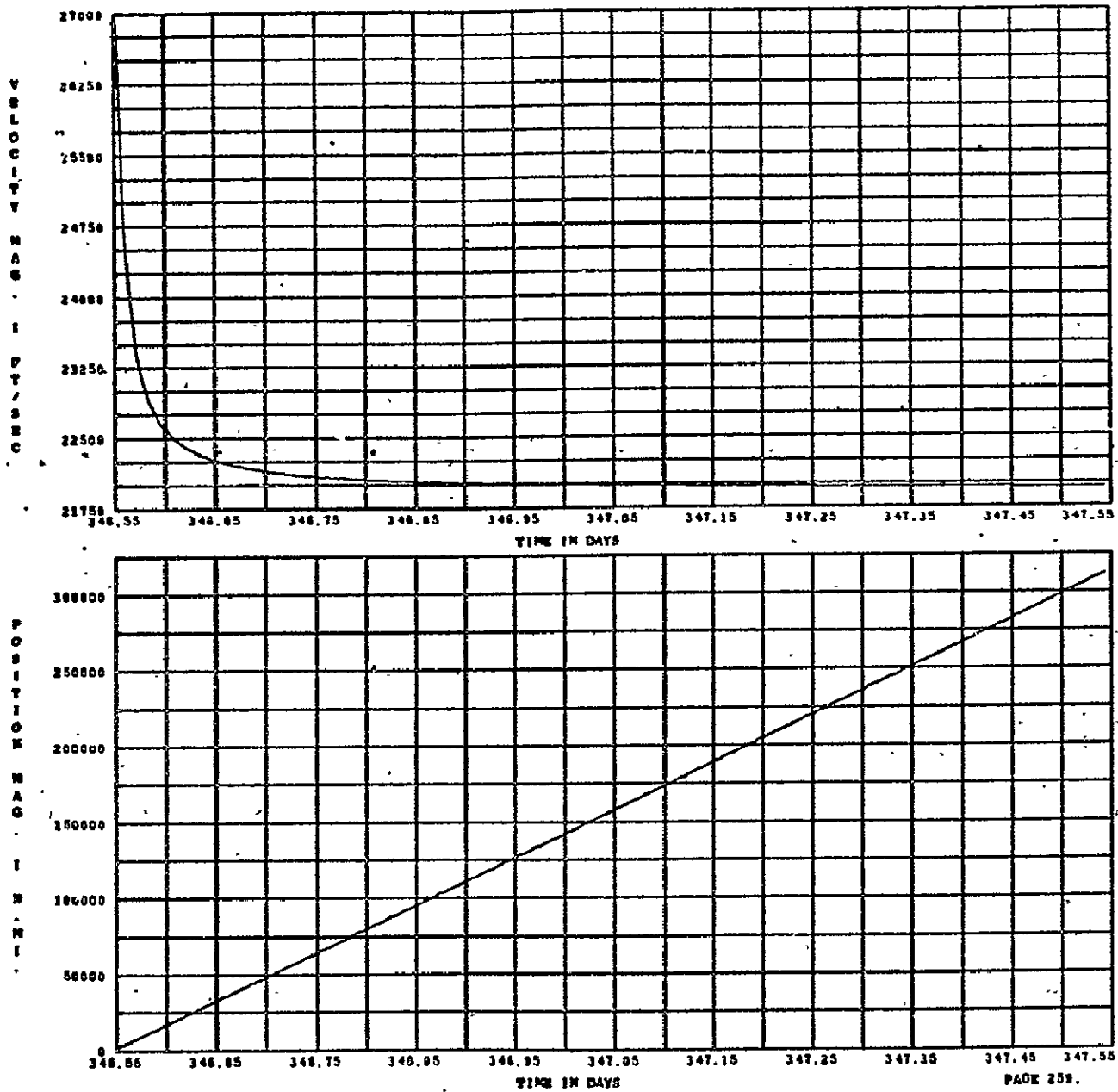
(b) Time histories of the Cartesian components of the velocity vector.

Figure 35.- Continued.



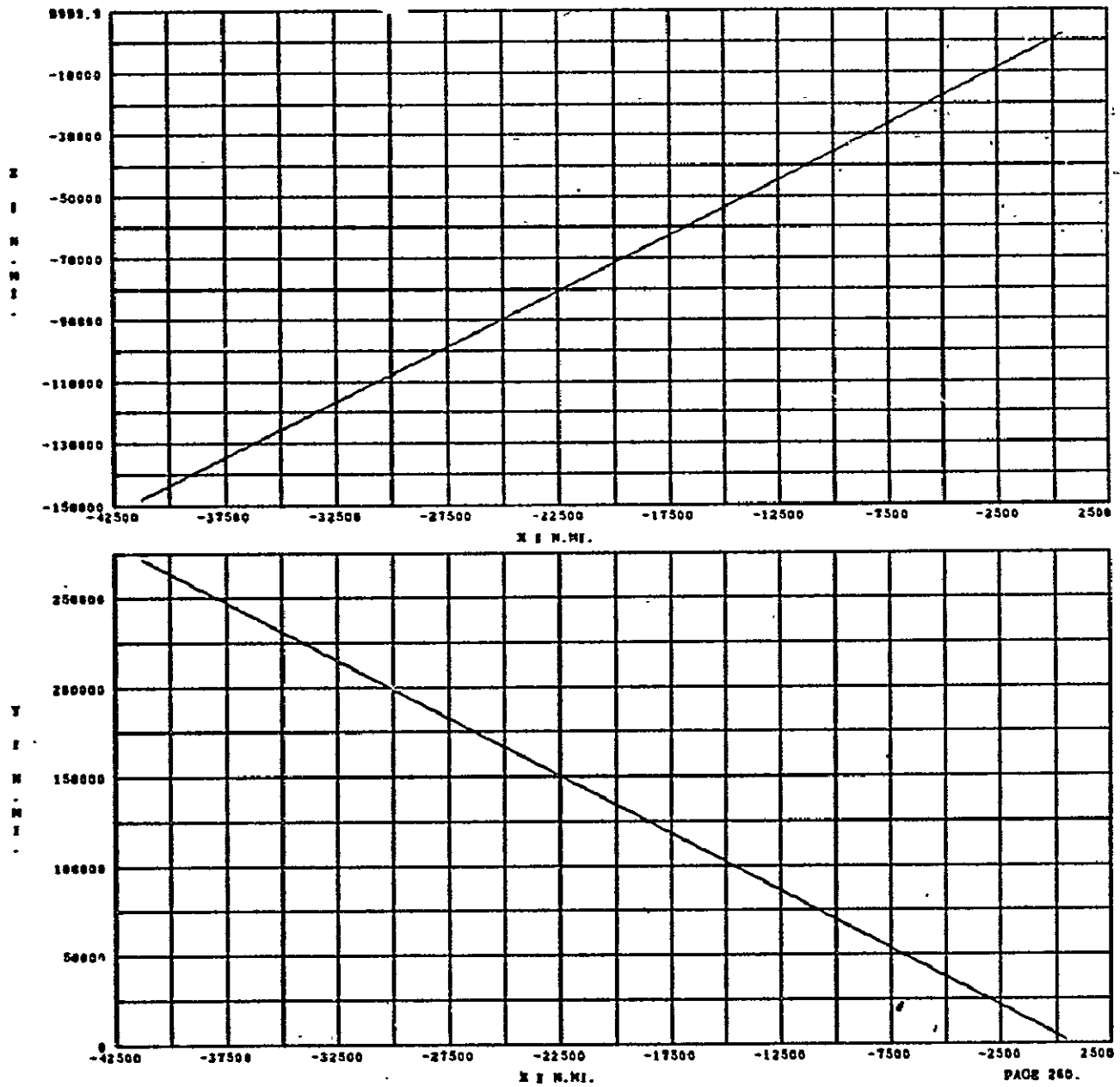
(c) Time histories of the true anomaly and mean anomaly.

Figure 35.- Continued.



(d) Time histories of the magnitudes of the position and velocity vectors.

Figure 35.- Continued.



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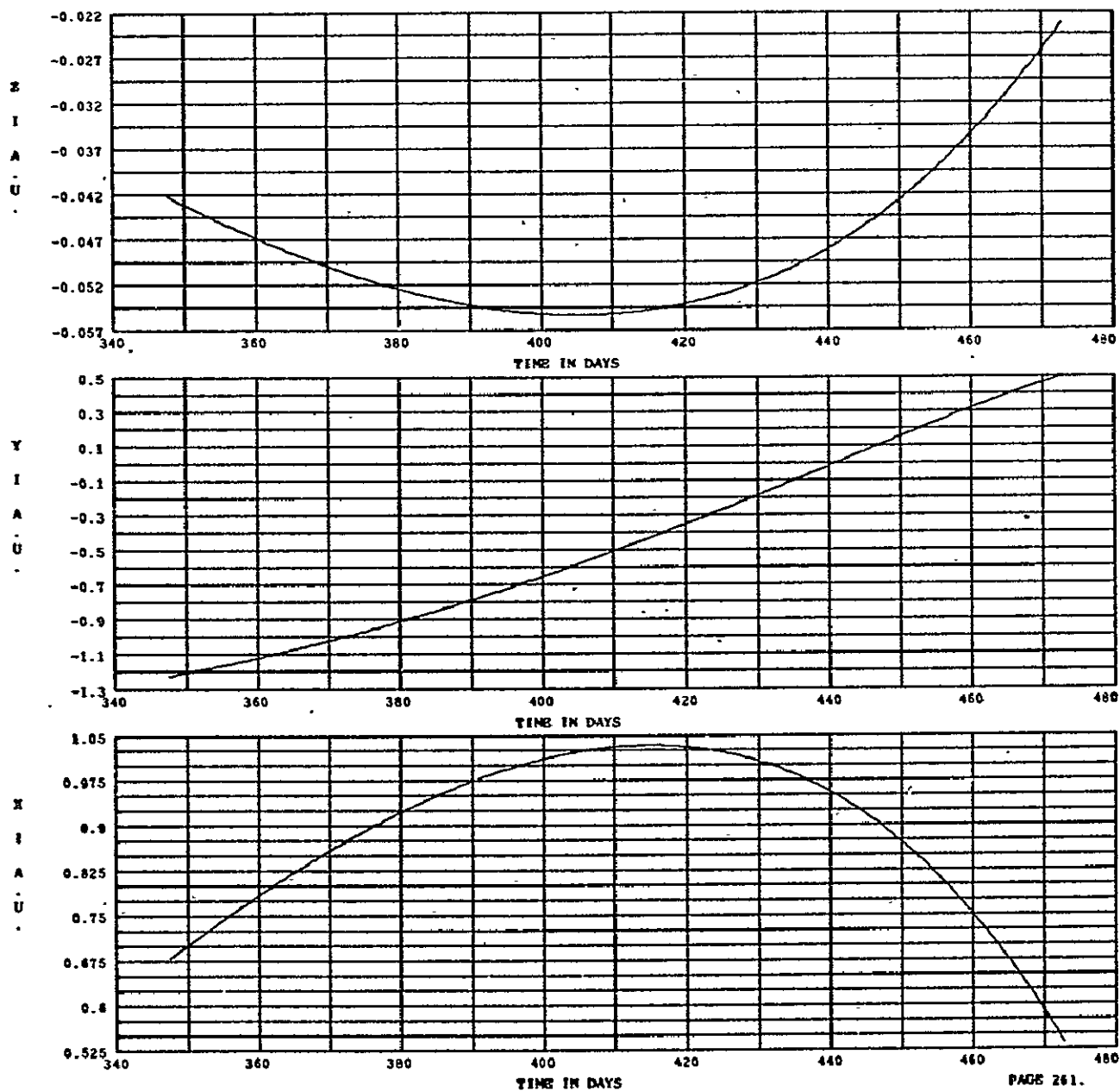
(e) Trajectory projections on the X-Y and X-Z planes.

Figure 35.- Concluded.

### 6.9 Mars-to-Venus Coast

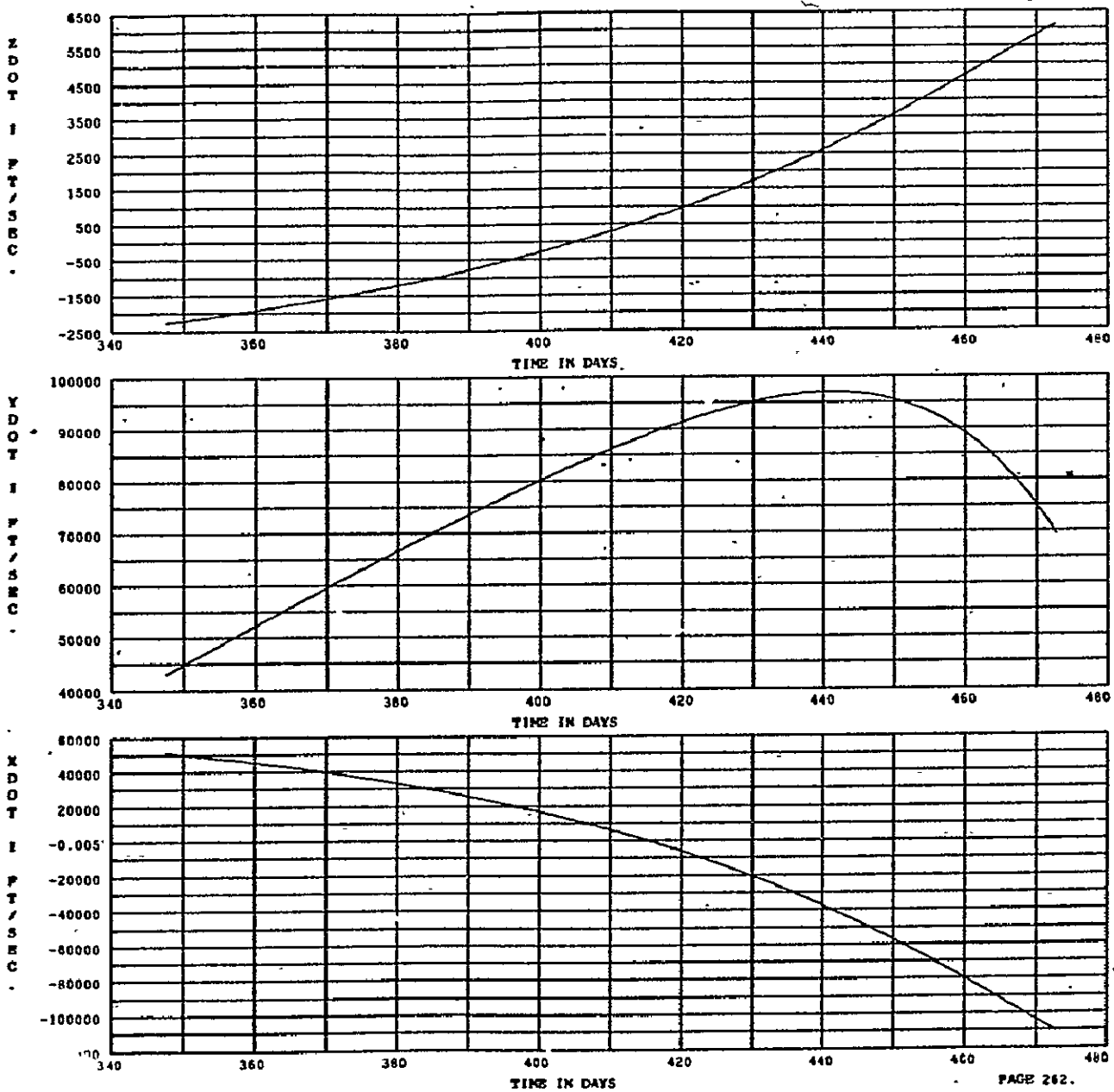
A time history of trajectory parameters for the Mars-to-Venus coast (Mars SOI to Venus SOI) is shown in figure 36. The heliocentric ecliptic coordinate system is used. The transfer time is 125 days, and the heliocentric transfer angle is  $102^\circ$ . The eccentricity and inclination of the transfer orbit are  $0.3925^\circ$  and  $2.9354^\circ$ , respectively. The spacecraft relative distances to the inner planets and the Sun are shown in figure 9 (section 8.3). The closest approach to Mercury during the Mars-to-Venus coast is approximately 0.8 A.U., while the spacecraft varies in distance from the Sun from approximately 1.4 to 0.7 A.U. The spacecraft/Earth distance varies from approximately 1.86 to 1.46 A.U.





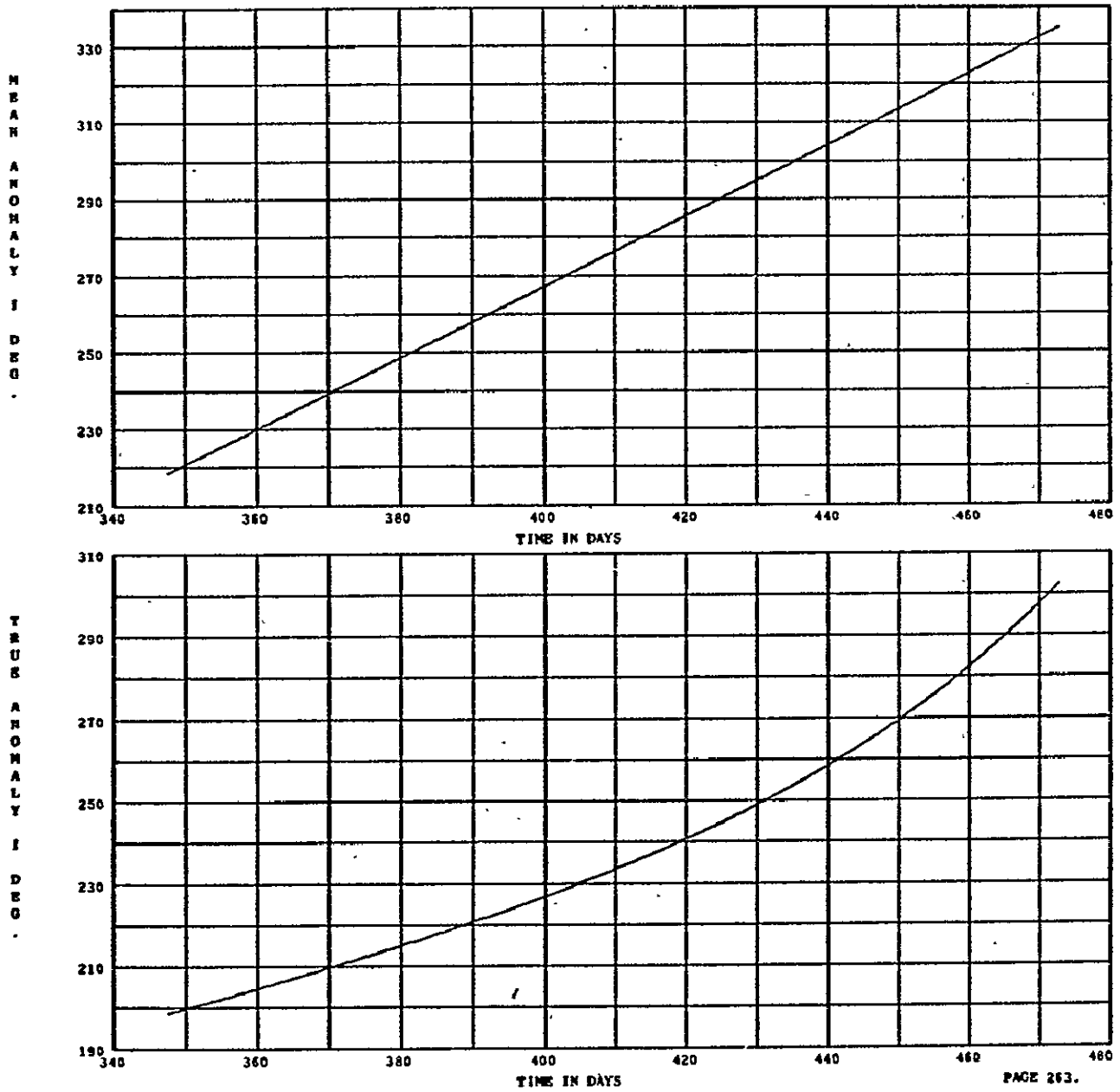
(a) Time histories of the Cartesian components of the position vector.

Figure 36.- Mars-to-Venus trajectory parameters (heliocentric ecliptic coordinate system) connecting spheres of influence boundaries.



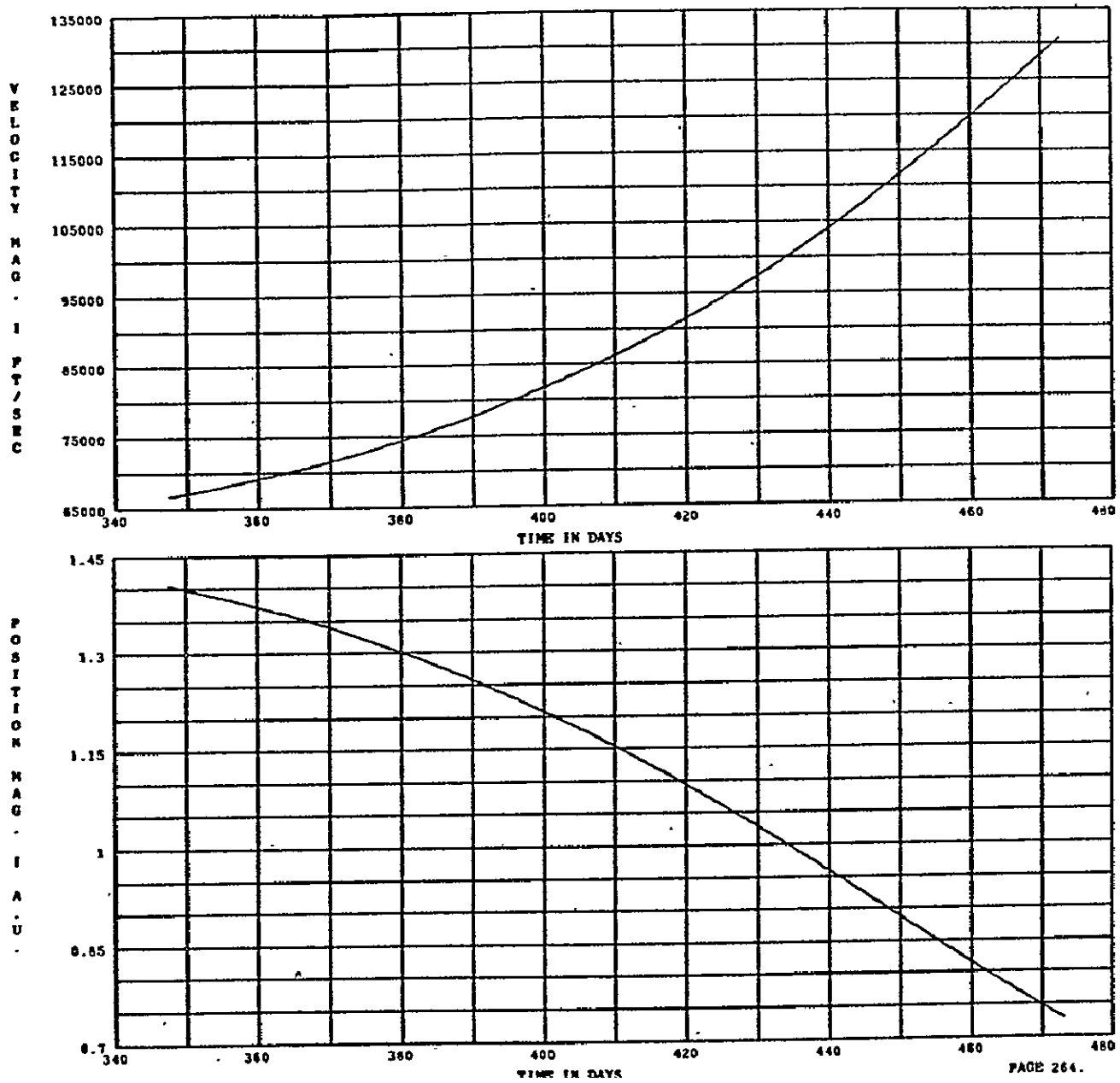
(b) Time histories of the Cartesian components of the velocity vector.

Figure 36.- Continued.



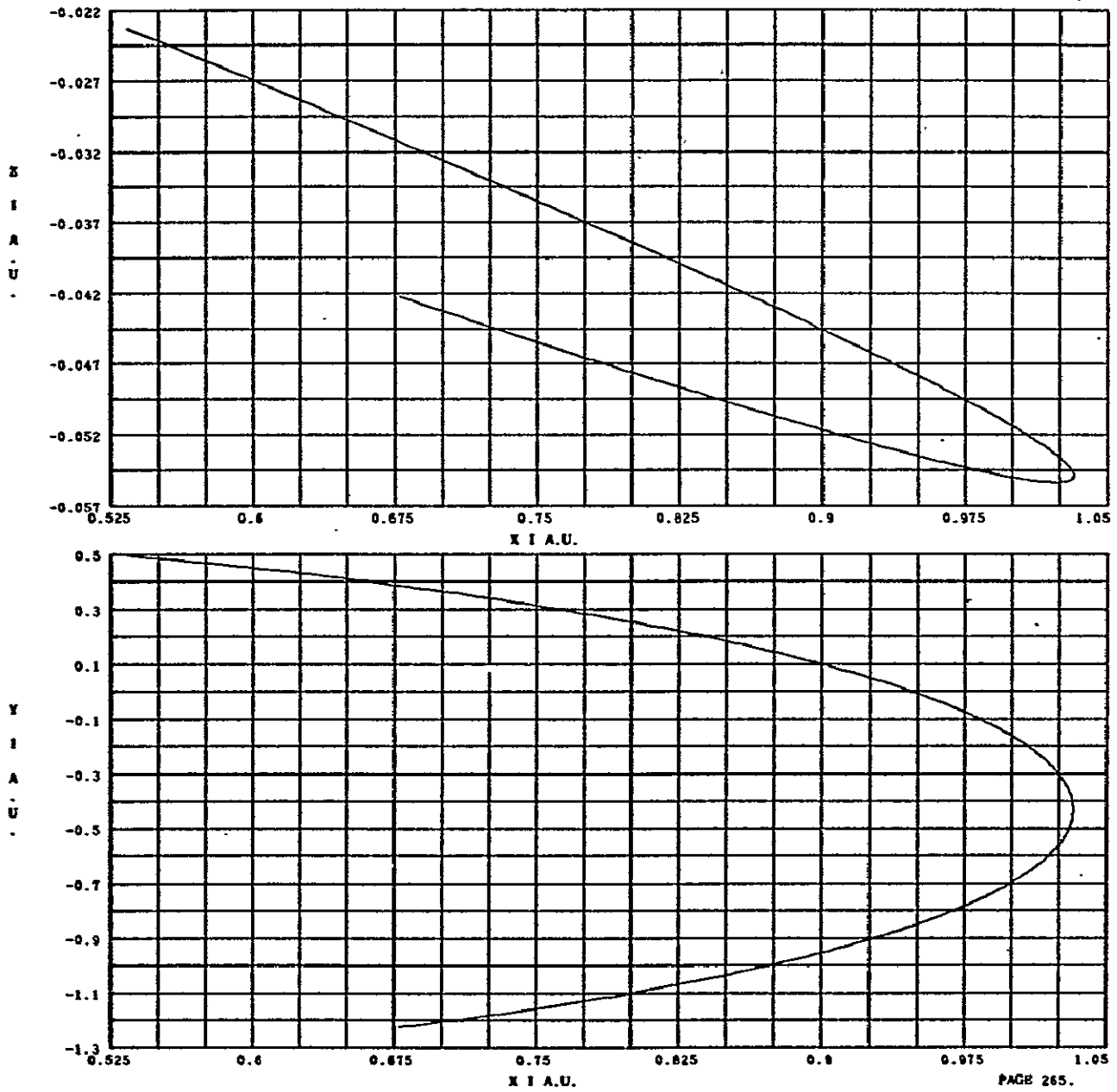
(c) Time histories of the true anomaly and mean anomaly.

Figure 36.- Continued.



(d) Time histories of the magnitudes of the position and velocity vectors.

Figure 36.- Continued.

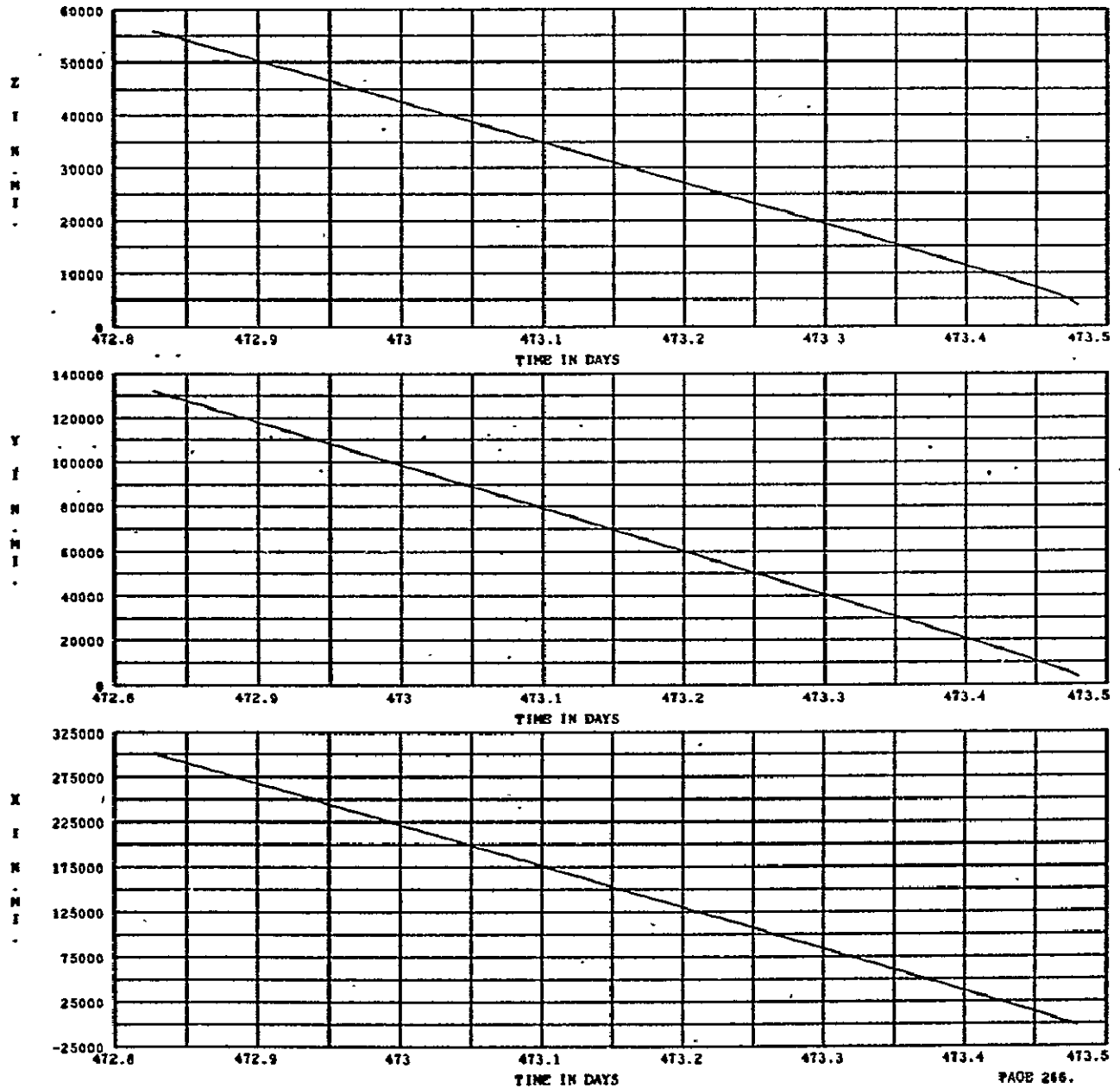


(e) Trajectory parameters on the X-Y and X-Z planes.

Figure 36.- Concluded.

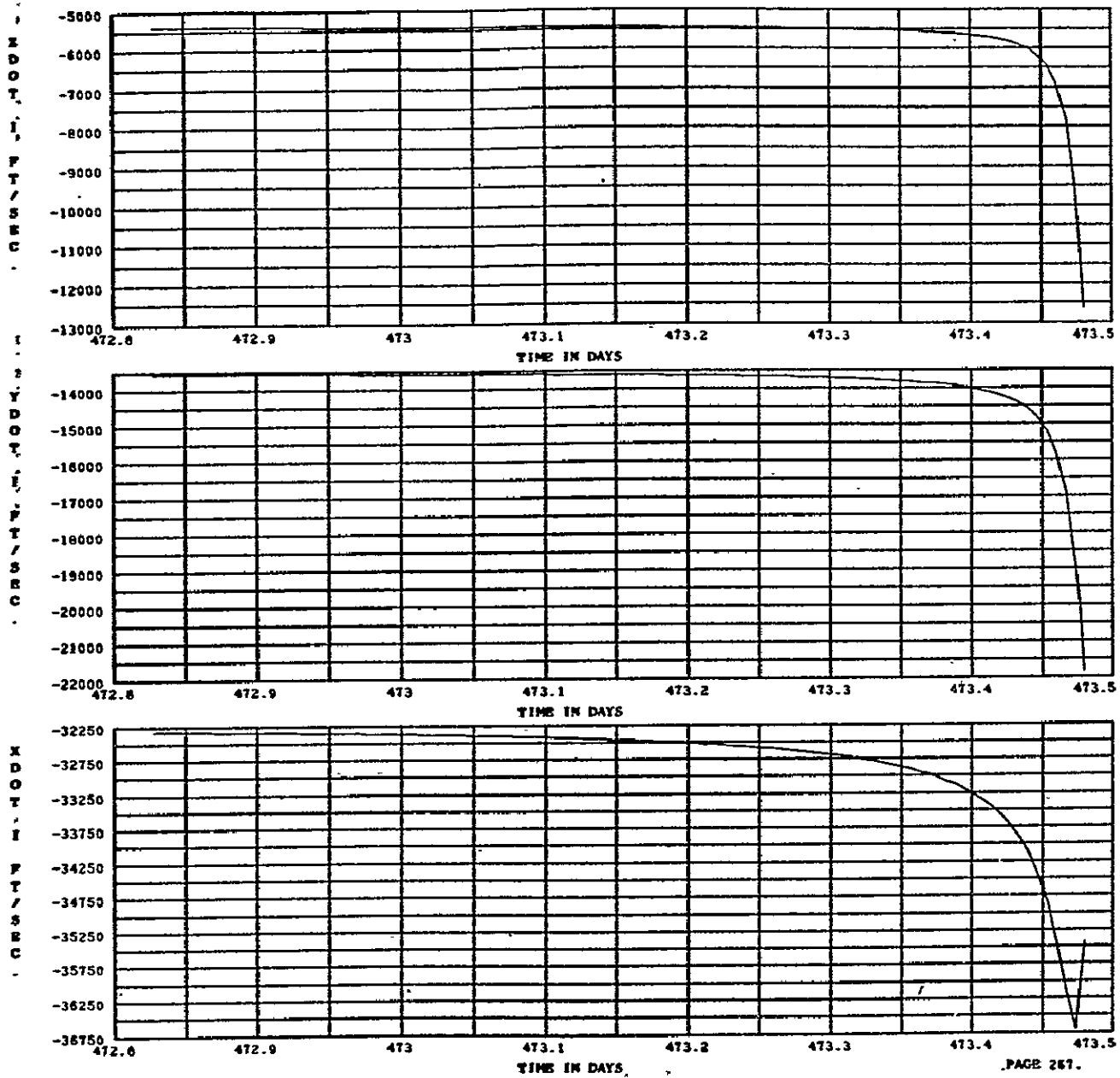
## 6.10 Venus Flyby

A time history of trajectory parameters for the arrival and departure trajectories at Venus is shown in figures 37 and 38, respectively. The coordinate system is the Venus-centered Earth equatorial system. The velocity at the Venus SOI (arrival and departure) is 35 400 fps. The closest approach is 2551 n. mi. at a velocity of 43 520 fps and an inclination of  $44.59^\circ$ . The total transfer angle (enter SOI to exit SOI) is  $200^\circ$ , and the transfer time is 31 hours. The spacecraft is within 25 000 n. mi. of Venus for 2.5 hours and is in sunlight except for 26 minutes of shadow occurring 45 minutes prior to periapsis. The vehicle enters the penumbra for 6 minutes, the umbra for 16 minutes, and the penumbra again for 4 minutes.



(a) Time histories of the Cartesian components of the position vector.

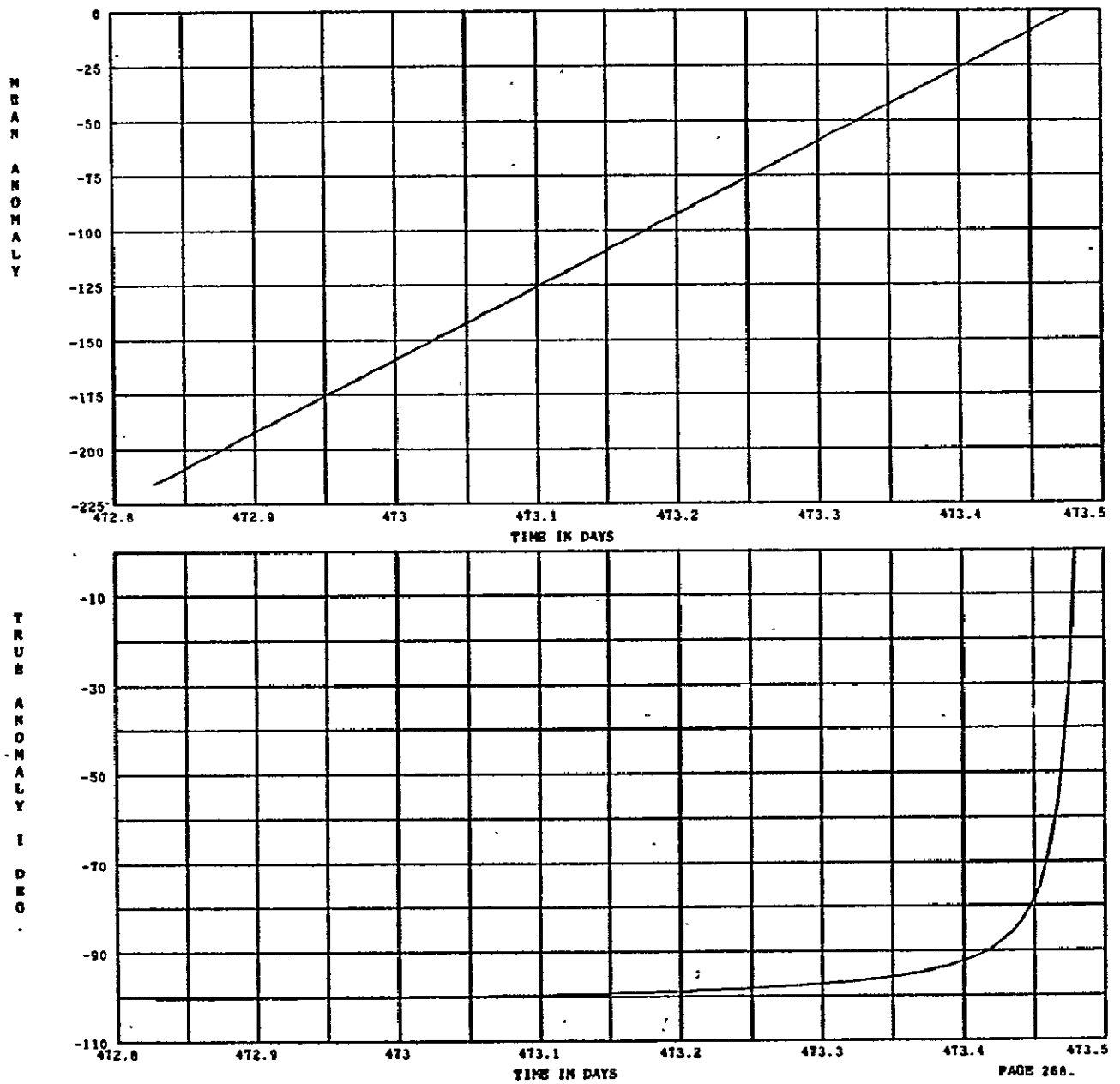
Figure 37.- Venus arrival trajectory parameters (planetocentric Earth equatorial coordinate system) sphere of influence to periapsis.



b) Time histories of the Cartesian components of the velocity vector.

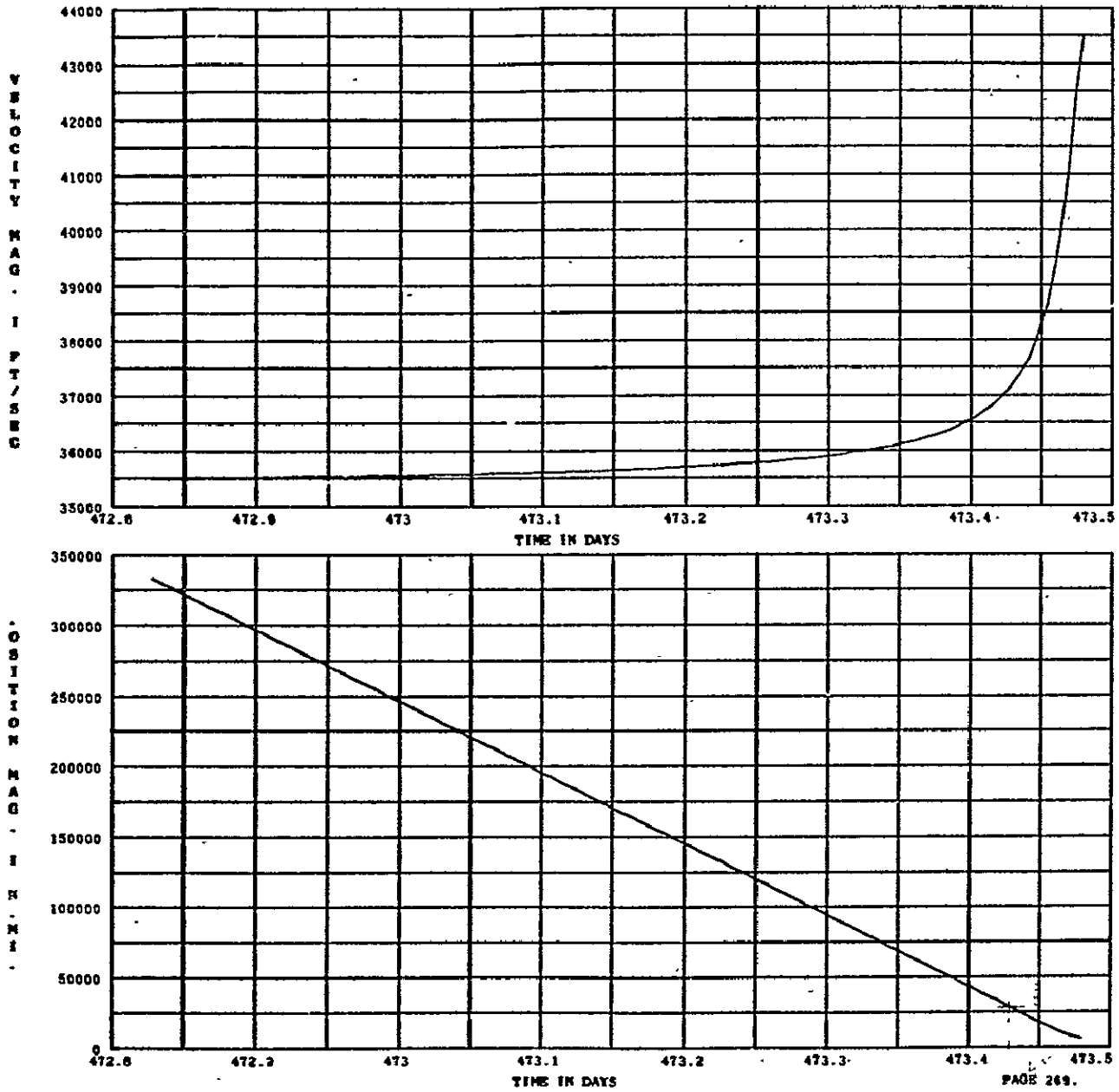
Figure 37.- Continued.





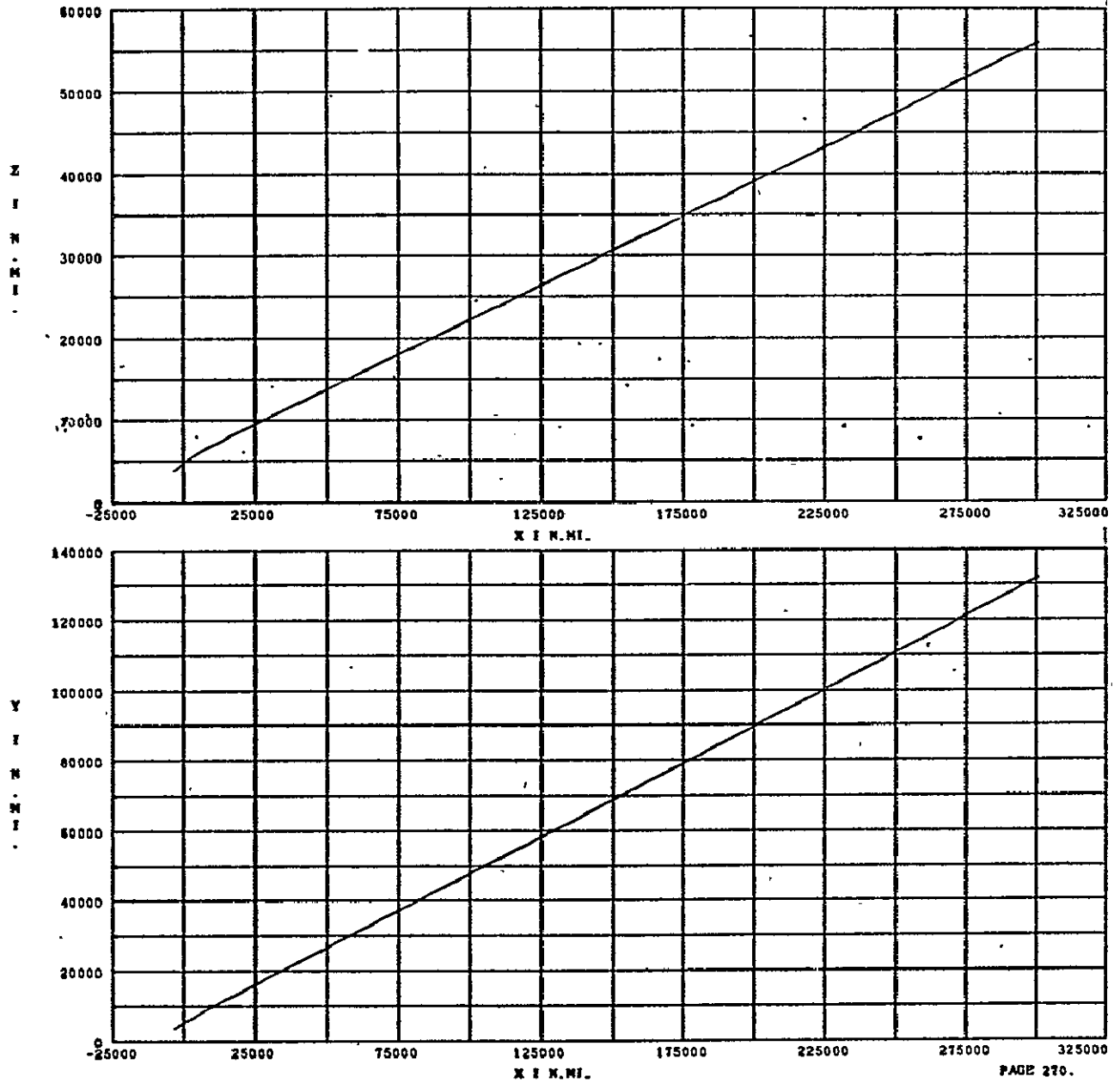
(c) Time histories of the true anomaly and mean anomaly.

Figure 37.- Continued.



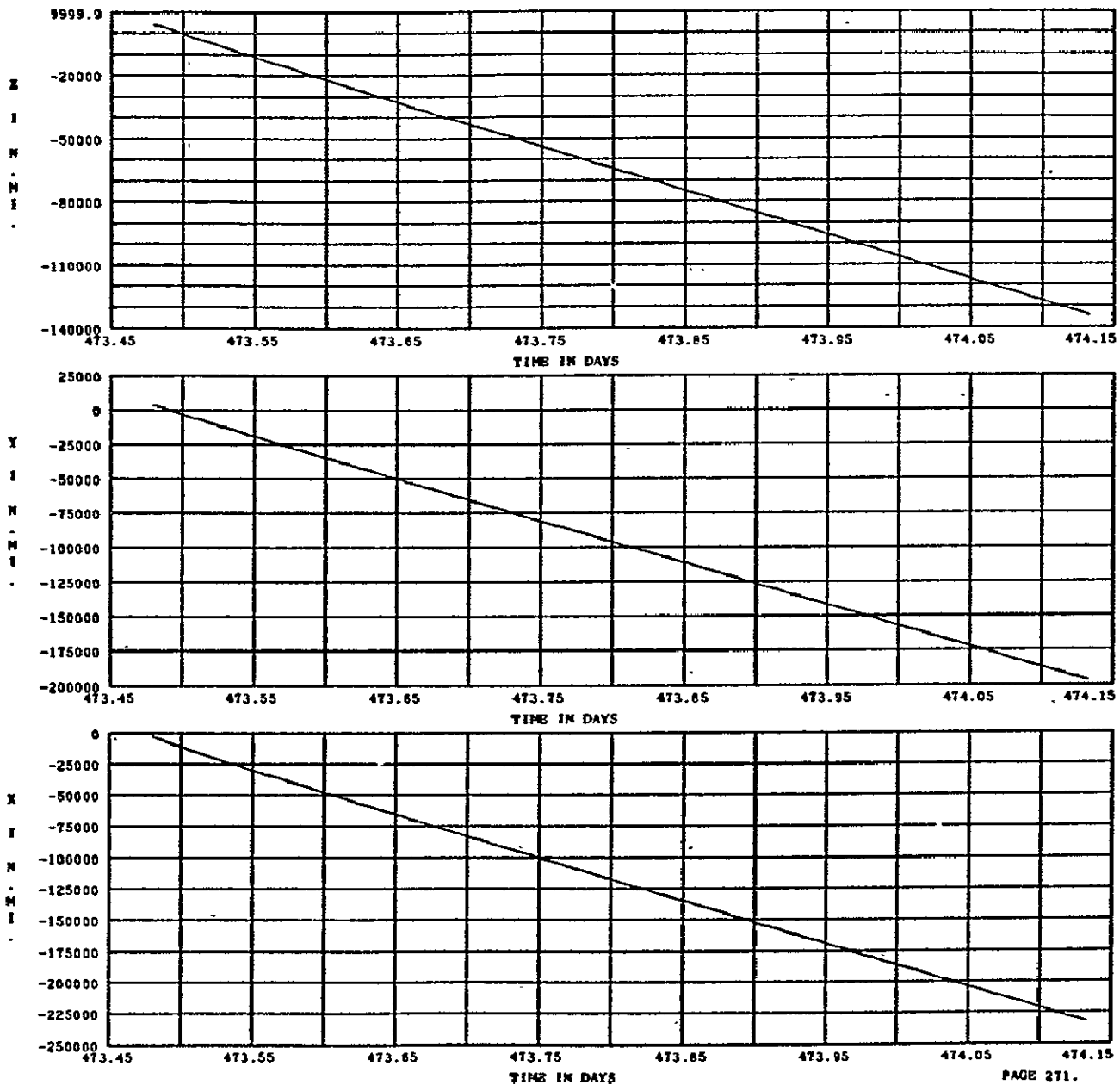
(d) Time histories of the magnitudes of the position and velocity vectors.

Figure 37.- Continued.



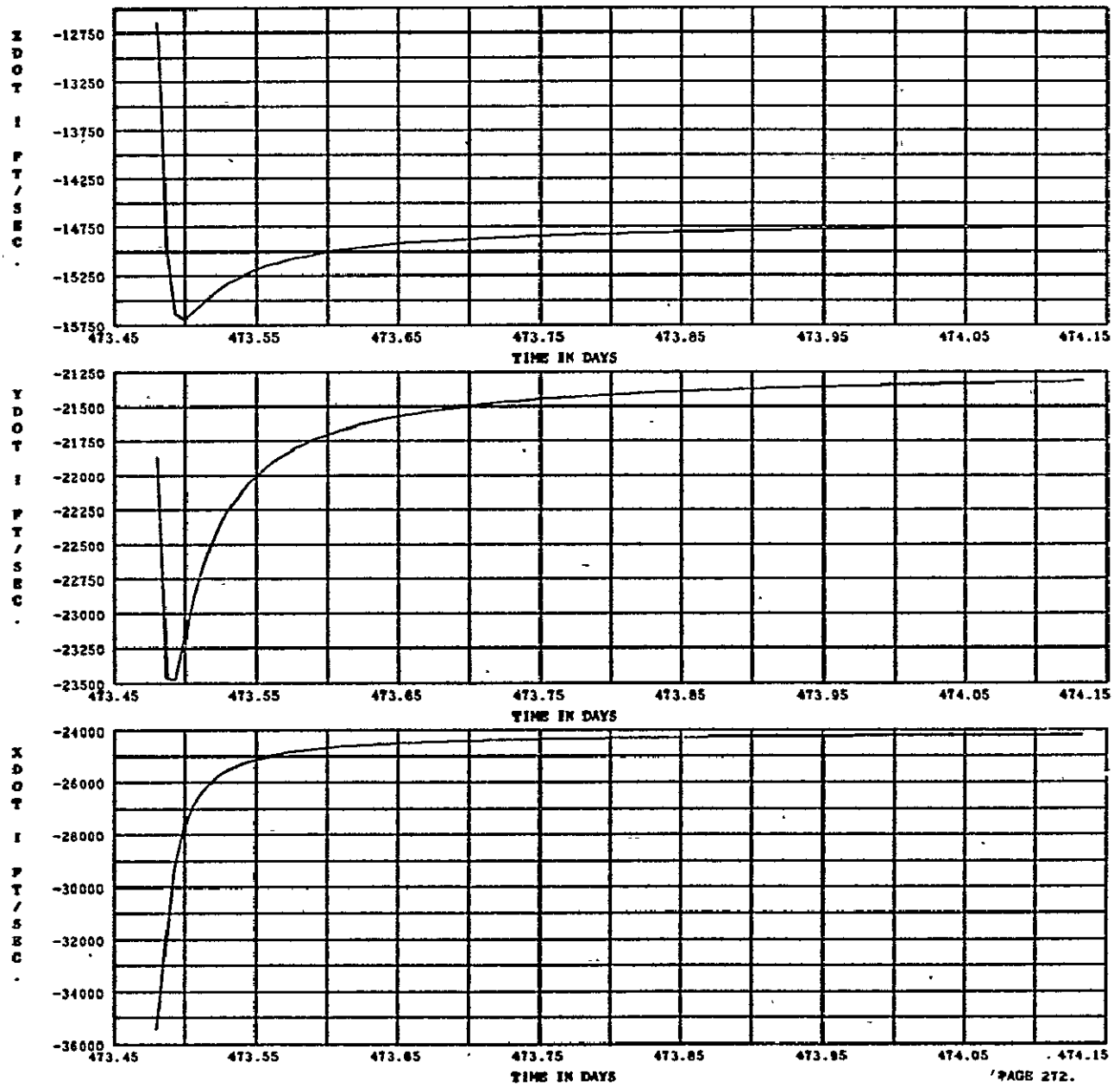
(e) Trajectory projections on the X-Y and X-Z planes.

Figure 37.- Concluded.



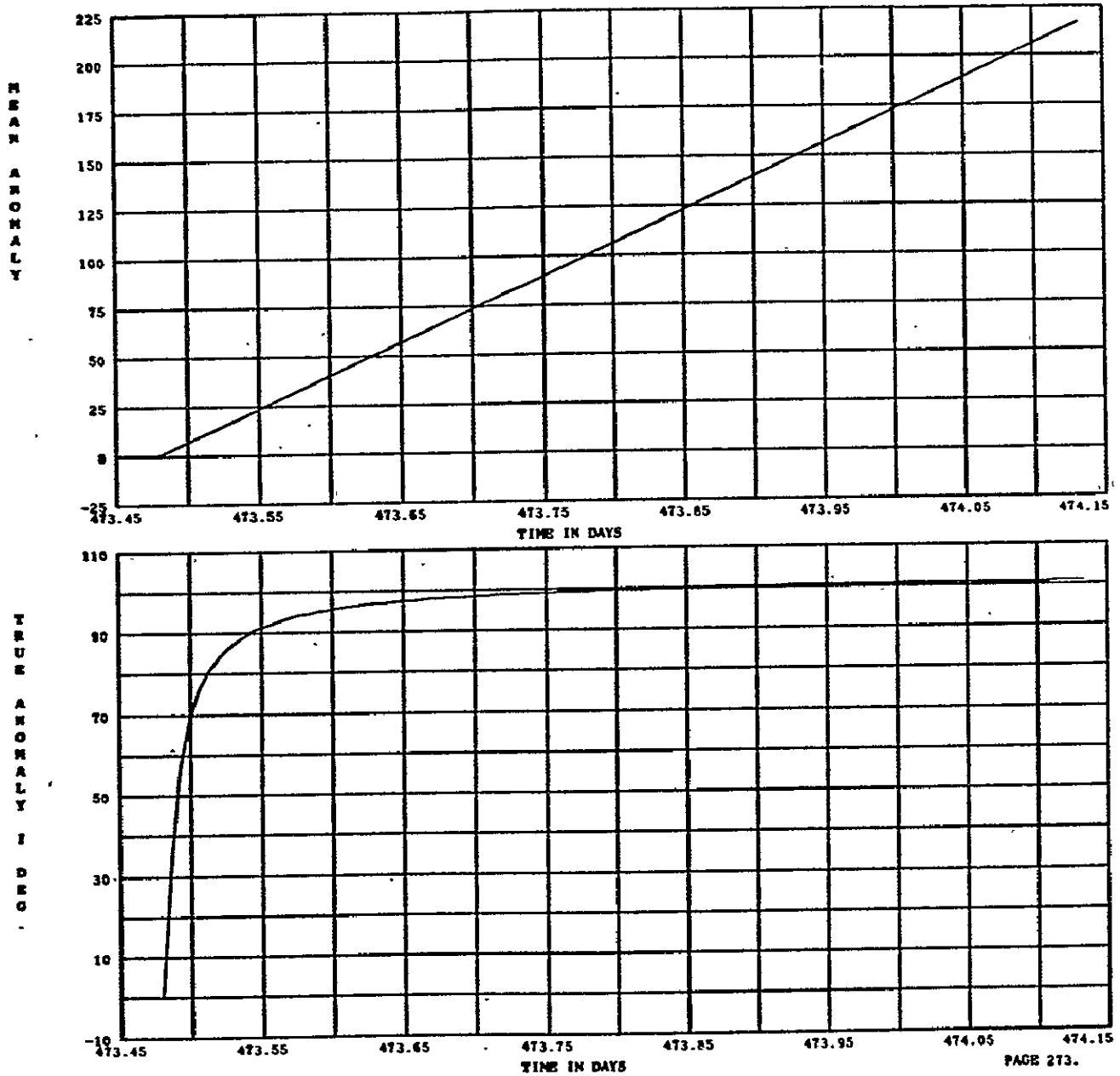
(a) Time histories of the Cartesian components of the position vector.

Figure 38.- Venus departure trajectory parameters (planetocentric Earth equatorial coordinate system) periapsis to sphere of influence.



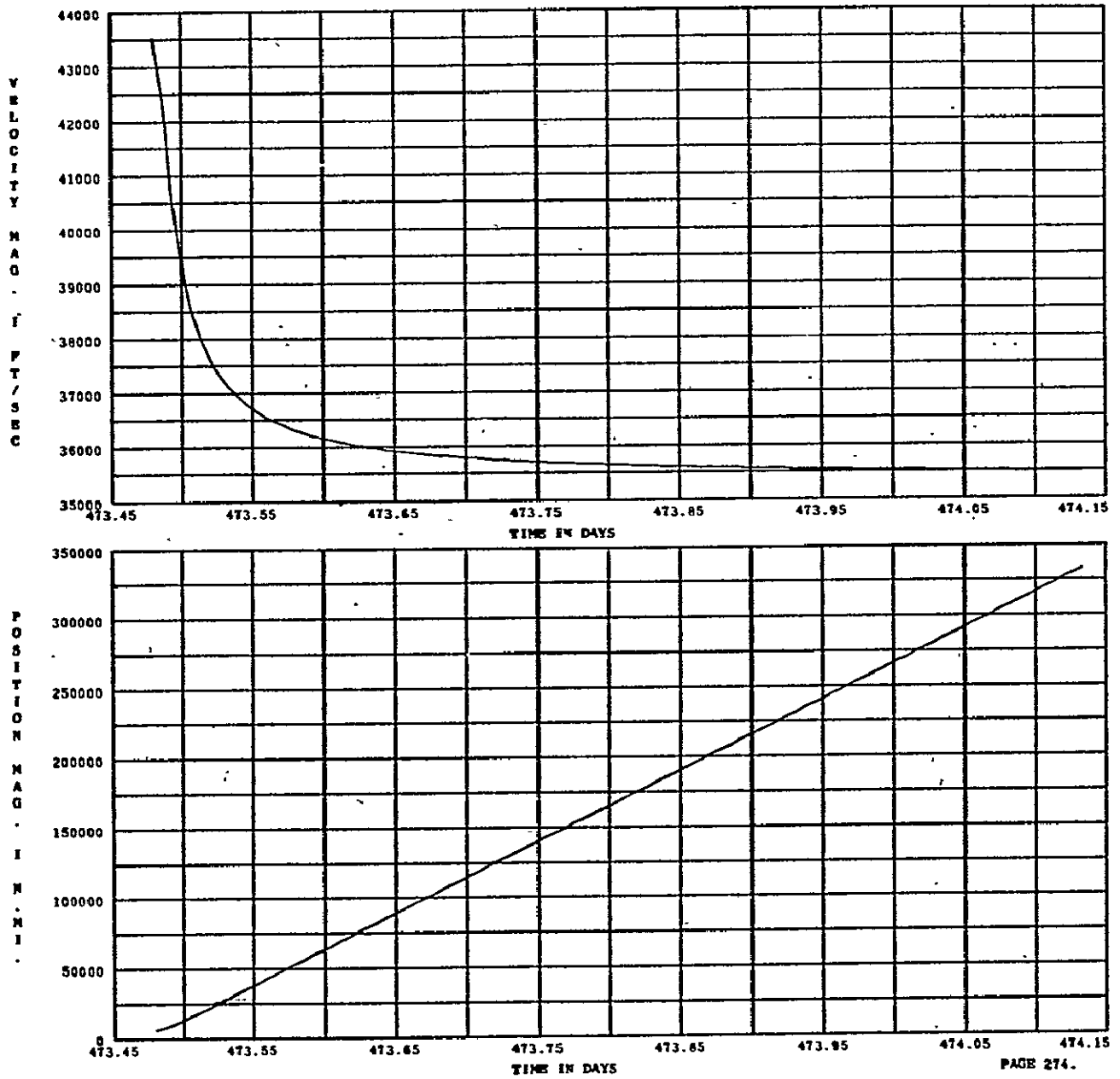
(b) Time histories of the Cartesian components of the velocity vector.

Figure 38.- Continued.



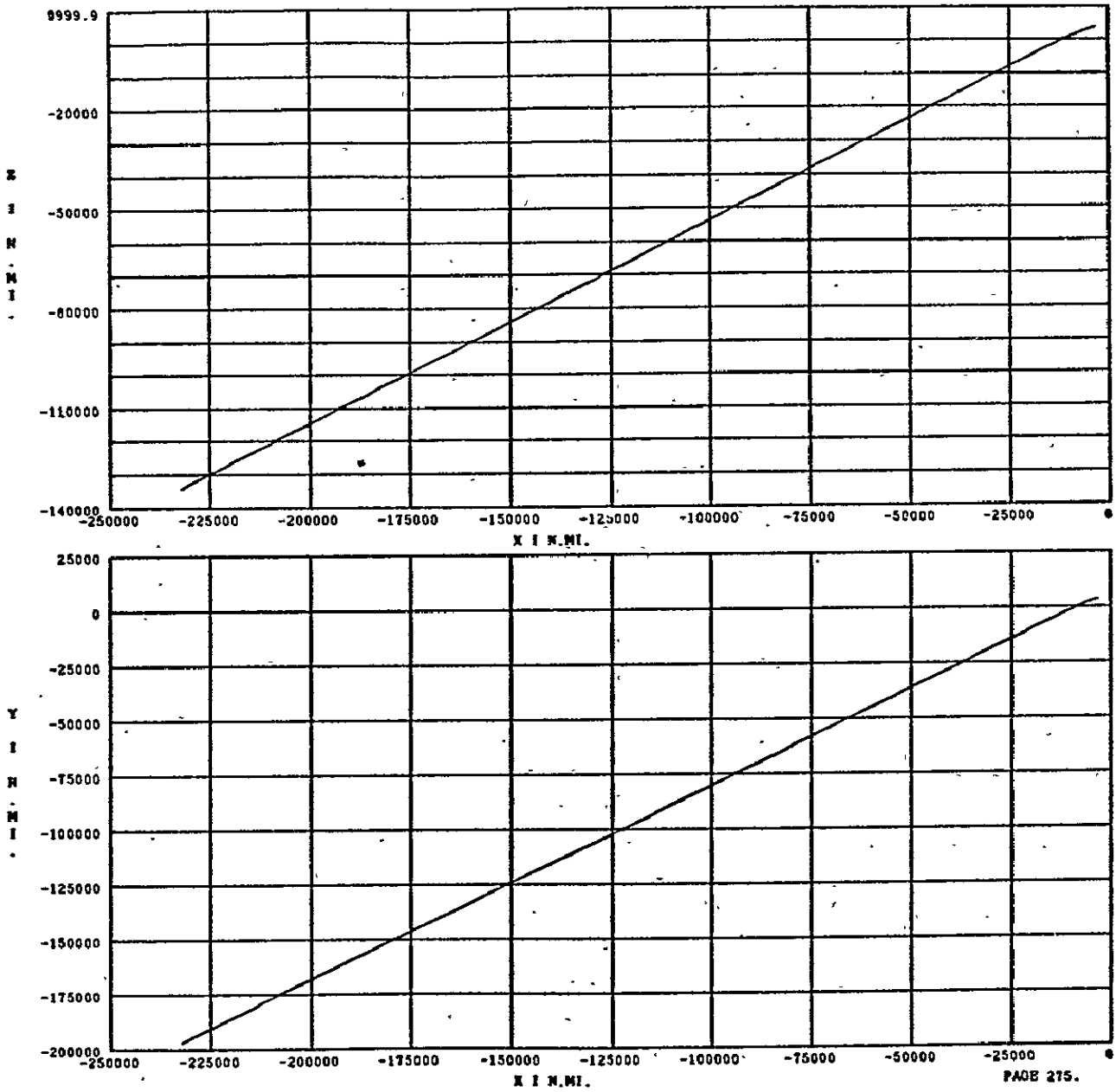
(c) Time histories of the true anomaly and mean anomaly.

Figure 38.- Continued.



(d) Time histories of the magnitudes of the position and velocity vectors.

Figure 38.- Continued.



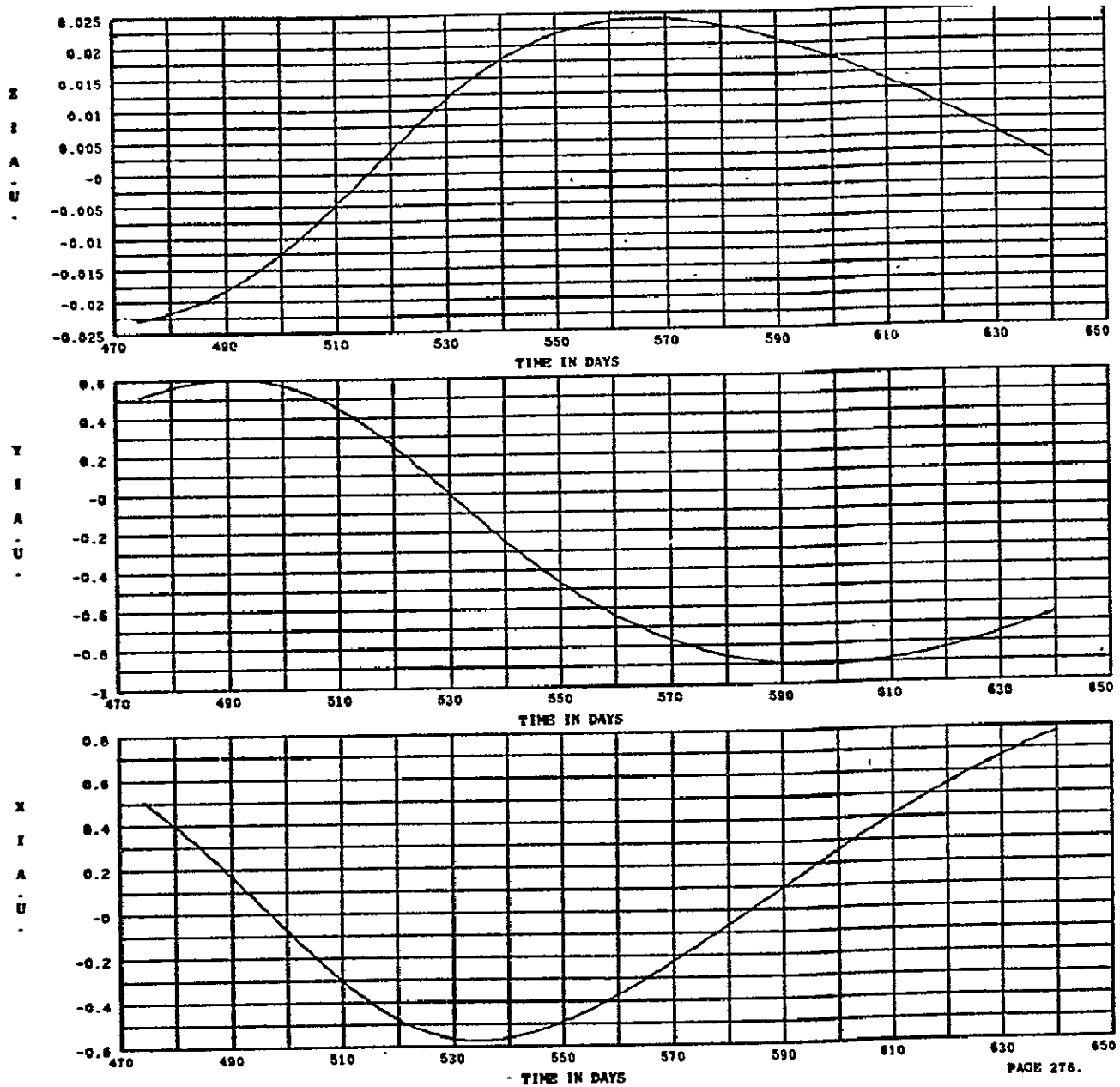
(e) Trajectory projections on X-Y and X-Z planes.

Figure 38.- Concluded.



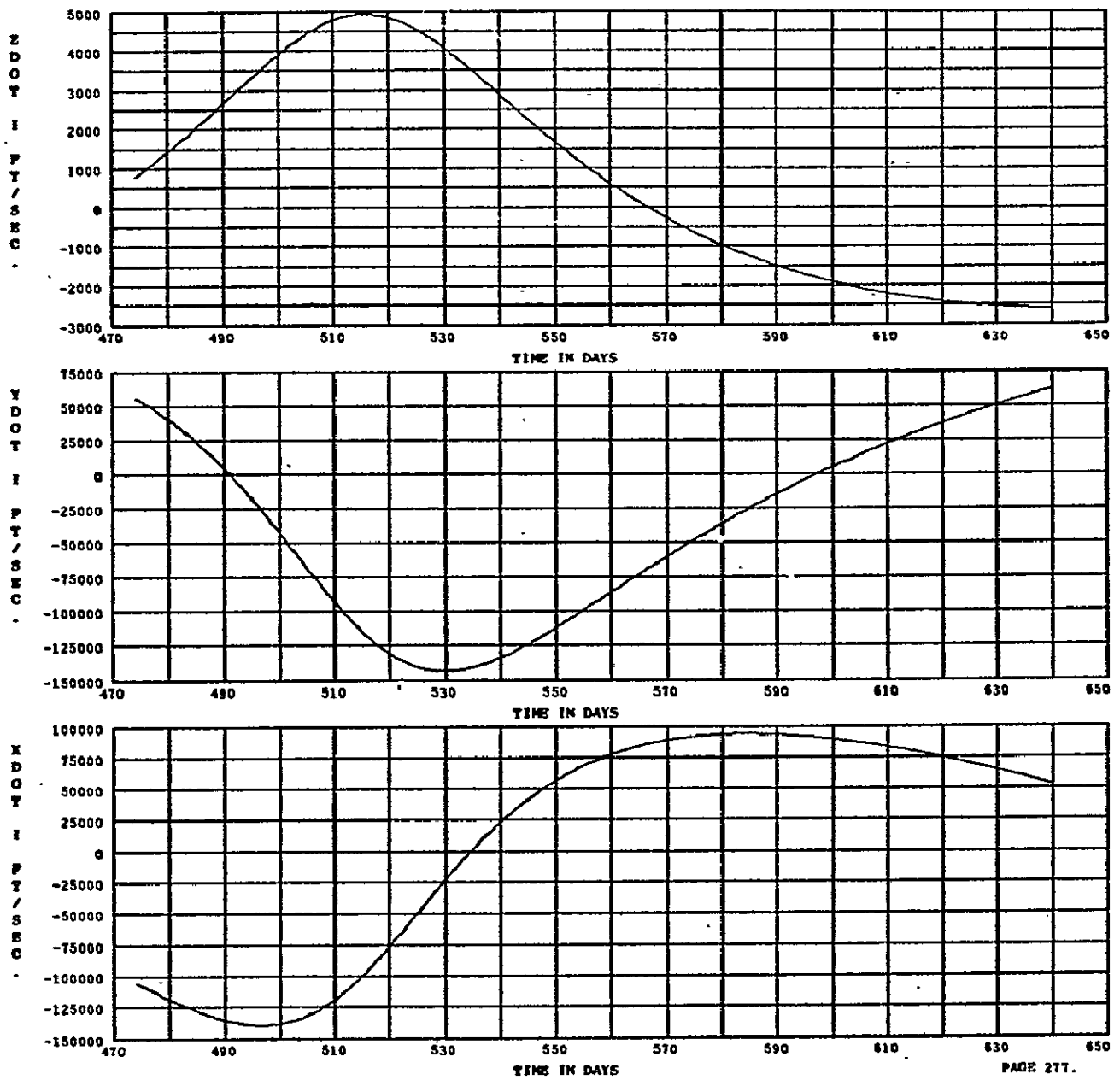
### 6.11 Venus-to-Earth Coast

A time history of trajectory parameters for the Venus-to-Earth coast (Venus SOI to Earth SOI) is shown in figure 39. The coordinate system is the heliocentric ecliptic system. The eccentricity and inclination of this heliocentric trajectory are  $0.3071^\circ$  and  $1.8456^\circ$ , respectively. The transfer angle is  $275^\circ$ , and the transfer time is 166 days. The spacecraft relative distances to the inner planets and the Sun are shown in figure 10 (section 8.3). The closest approach to Mercury is 0.2 A.U. during this portion of the mission. The spacecraft varies in distance from the Sun from approximately 0.55 to 1.0 A.U.



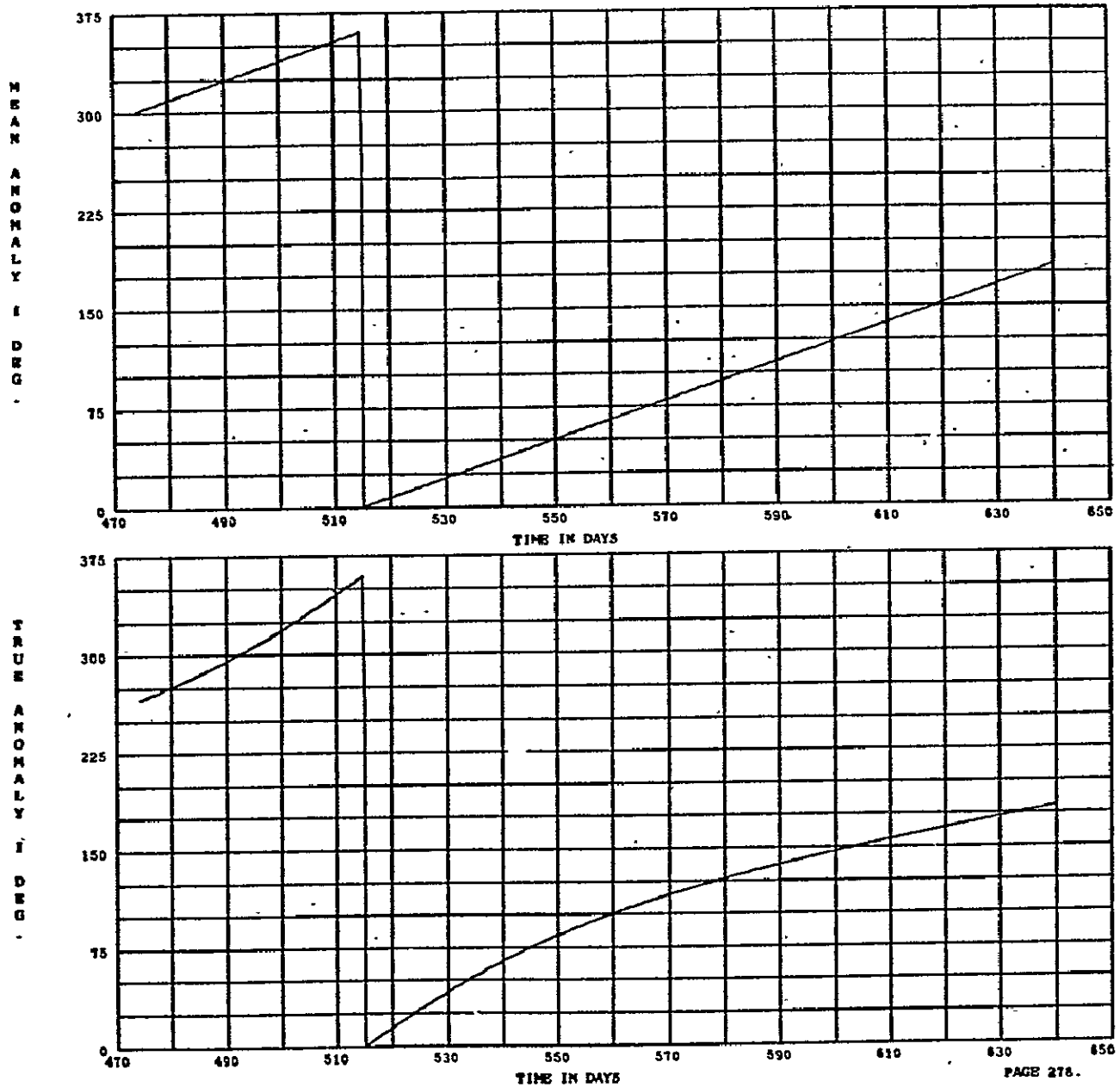
(a) Time histories of the Cartesian components of the position vector.

Figure 39. -- Venus-to-Earth trajectory parameters (heliocentric ecliptic coordinate system) connecting spheres of influence boundaries.



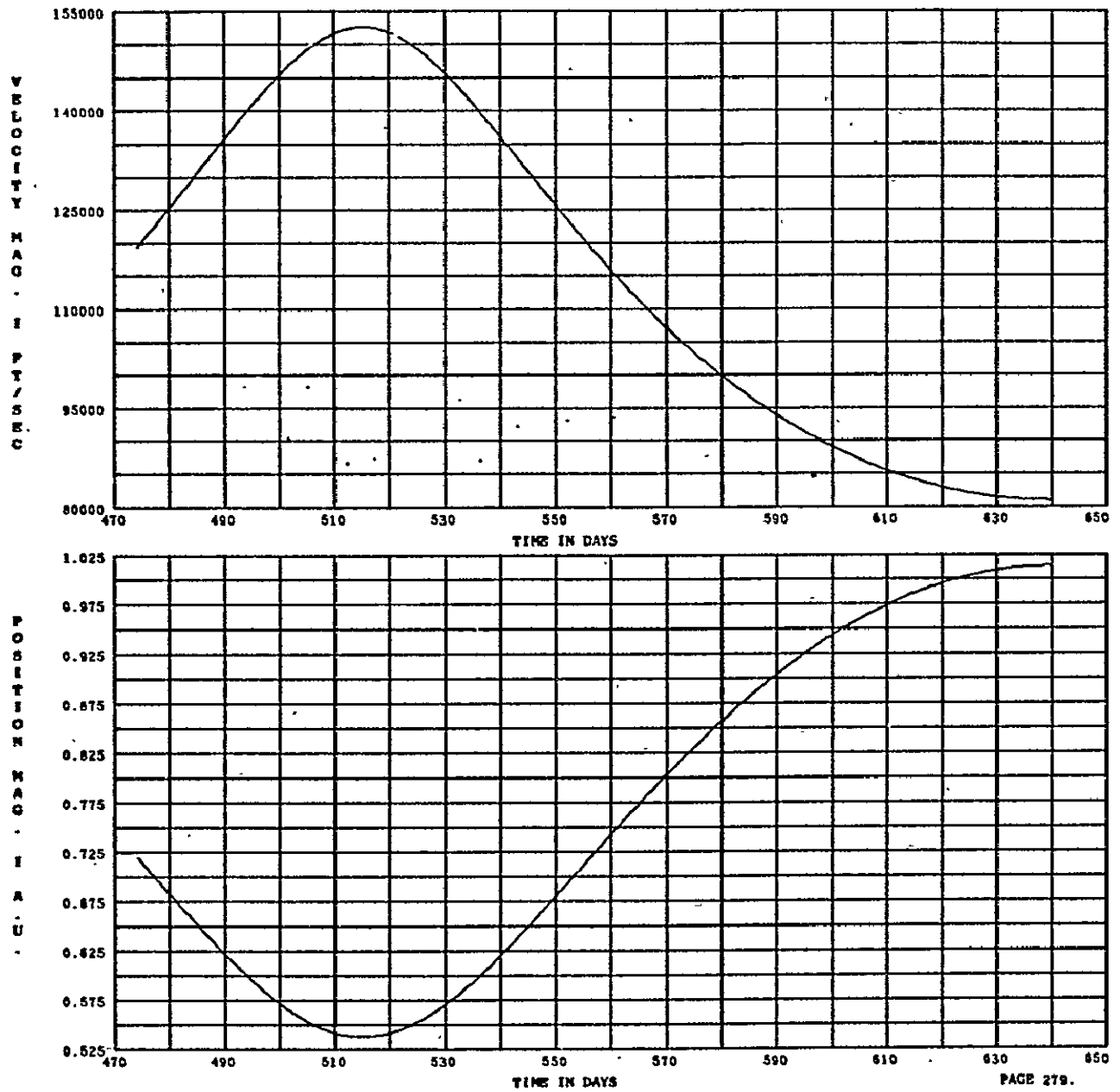
(b) Time histories of the Cartesian components of the velocity vector.

Figure 39.- Continued.



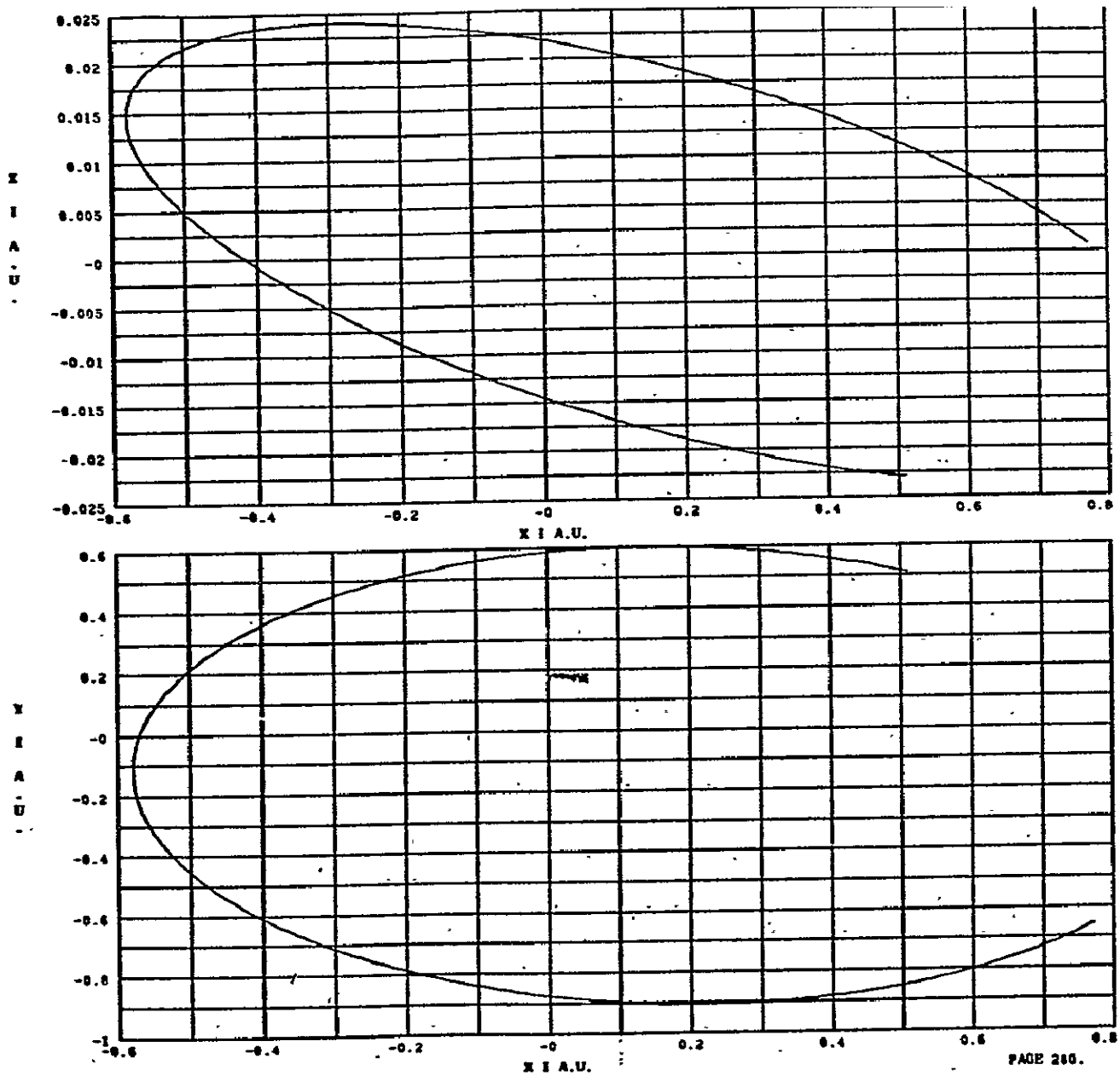
(c) Time histories of the true anomaly and mean anomaly.

Figure 39.-Continued.



(d) Time histories of the magnitudes of the position and velocity vectors.

Figure 39.- Continued.

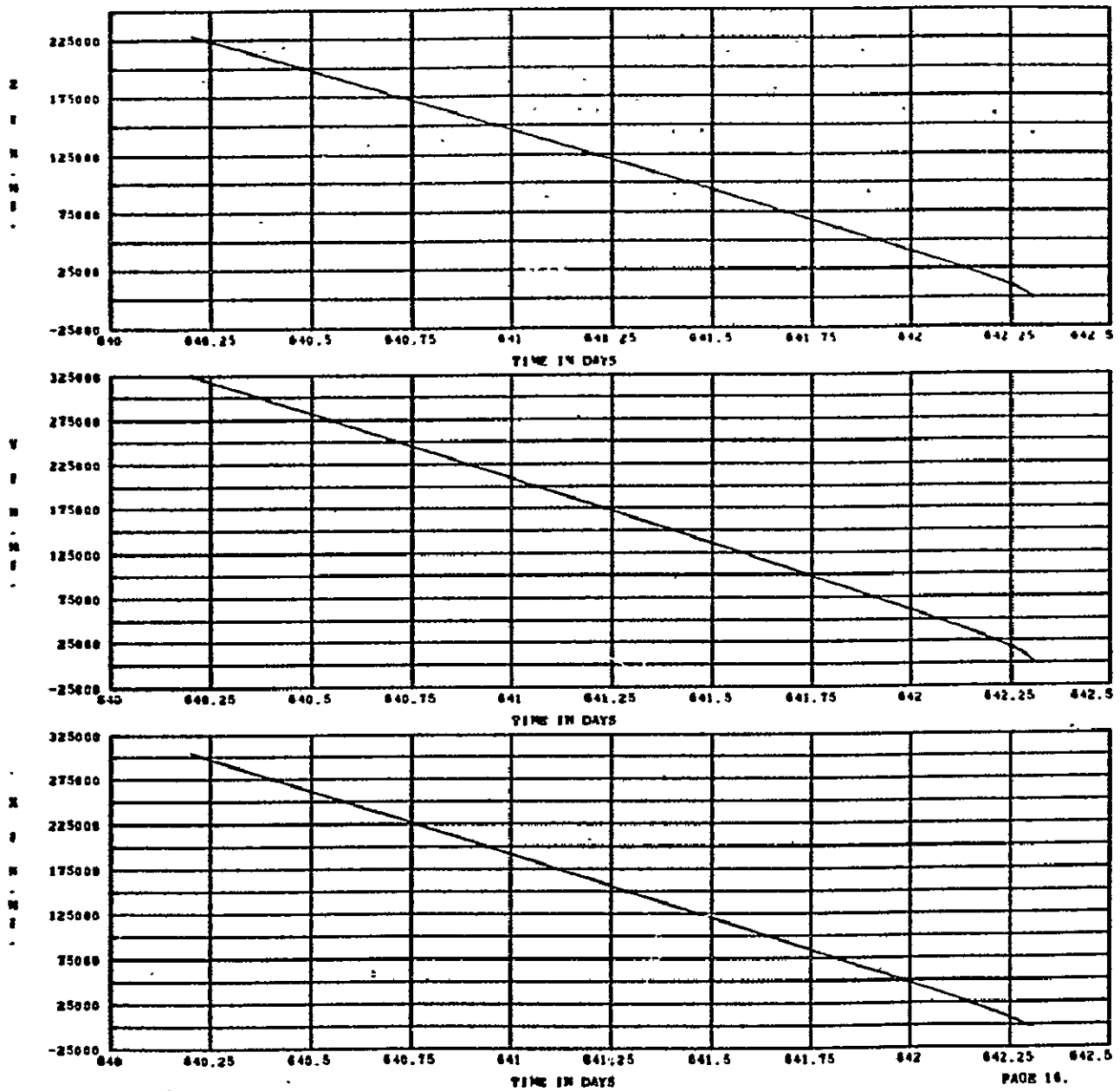


(e) Trajectory projections on the X-Y and X-Z planes.

Figure 39. - Concluded.

### 6.12 Earth Approach

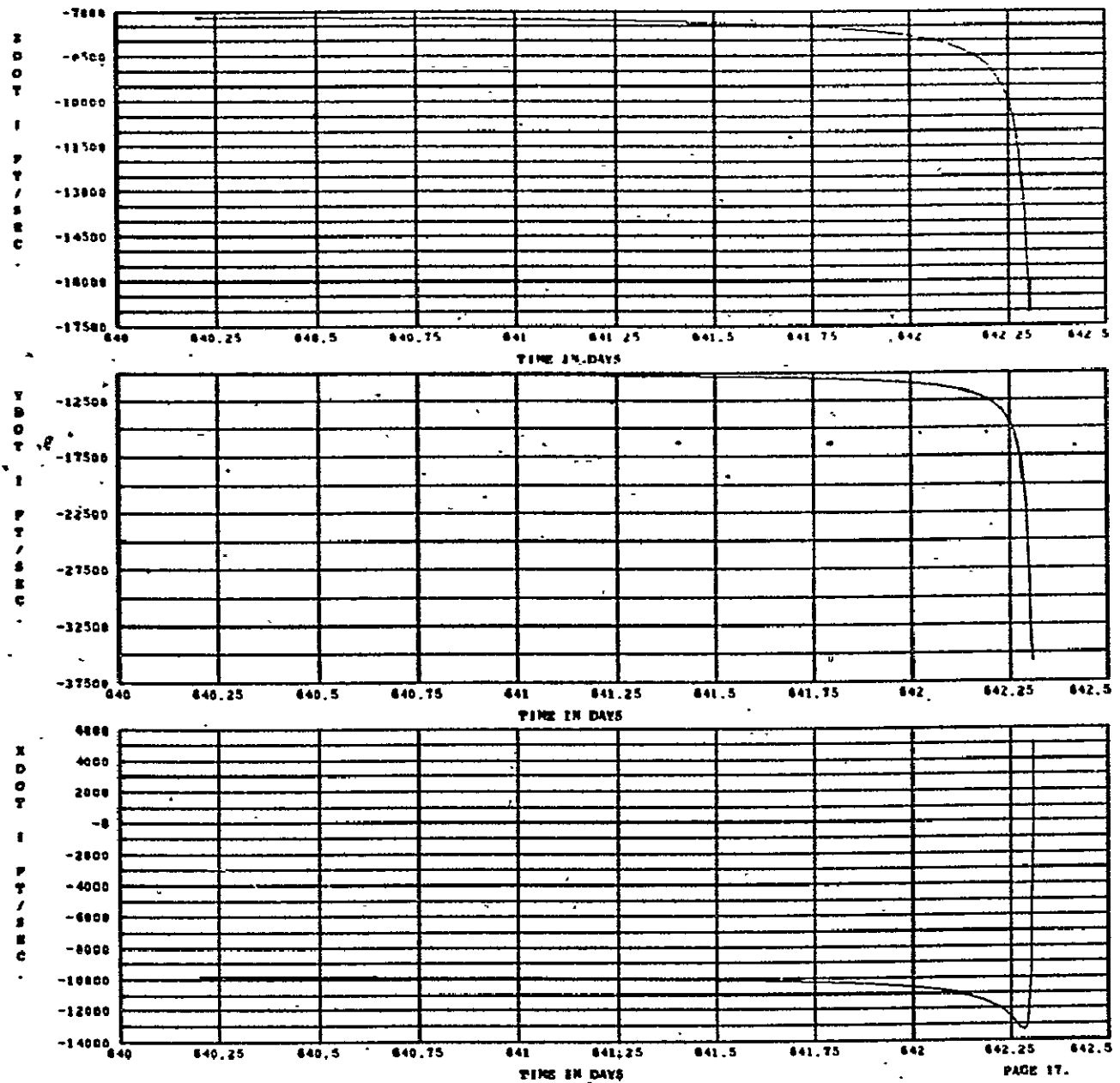
A time history of trajectory parameters for the trajectory from the Earth SOI to periapsis is shown in figure 40. The coordinate system is the Earth equatorial system. The transfer angle is  $136^\circ$ , and the transfer time is 50.6 hours. The velocity at the Earth SOI is 15 870 fps, and the entry velocity at the 400 000-foot altitude is 39 530 fps. The inclination of this trajectory is  $28.2^\circ$ . Entry interface occurs at  $14.2^\circ\text{S}$  latitude and  $165.7^\circ\text{W}$  longitude. The aerodynamic entry phase was not simulated.



(a) Time histories of the Cartesian components of the position vector.

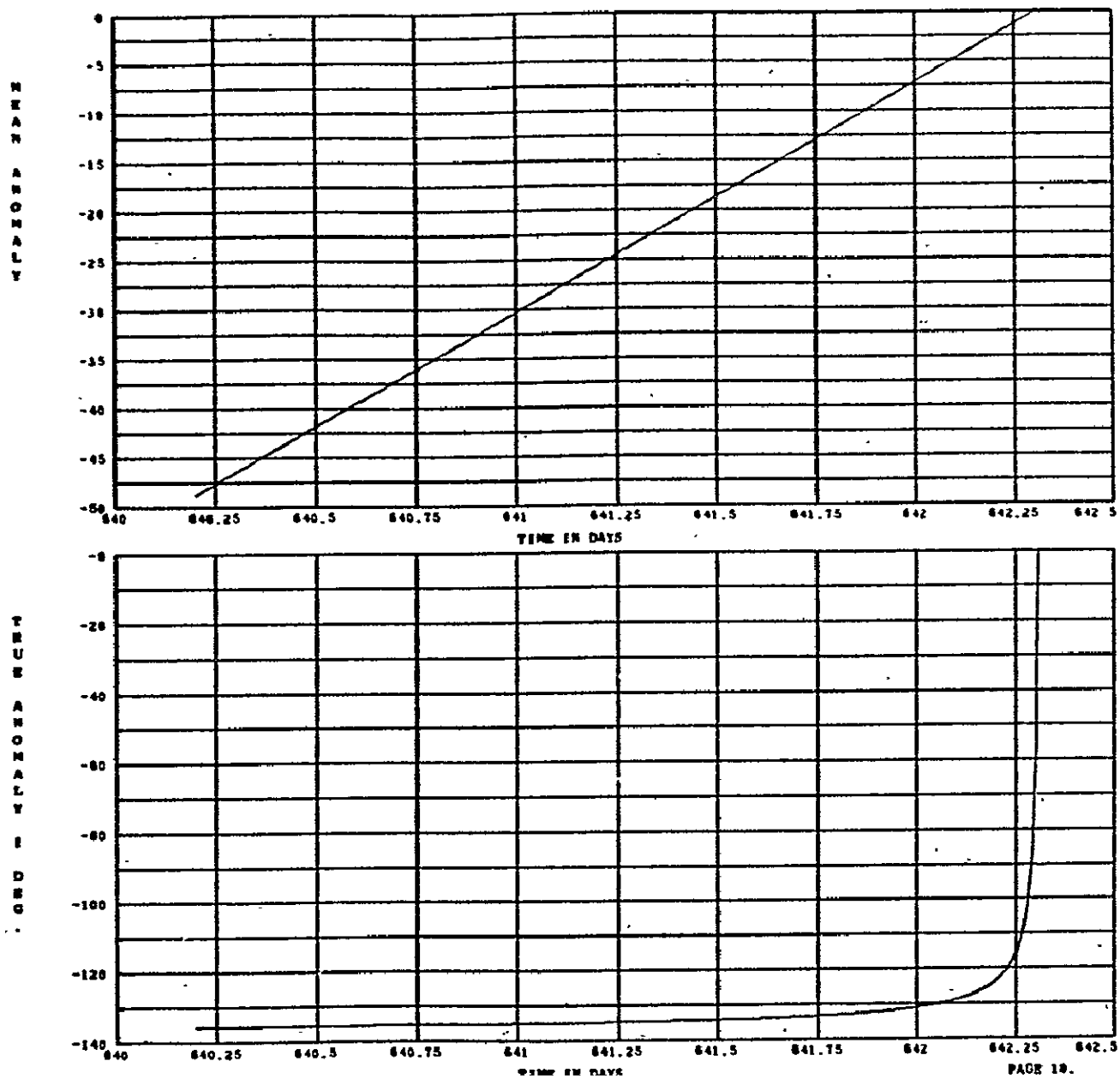
Figure 40.- Earth arrival trajectory parameters (planetocentric equatorial coordinate system) sphere of influence to periapsis.





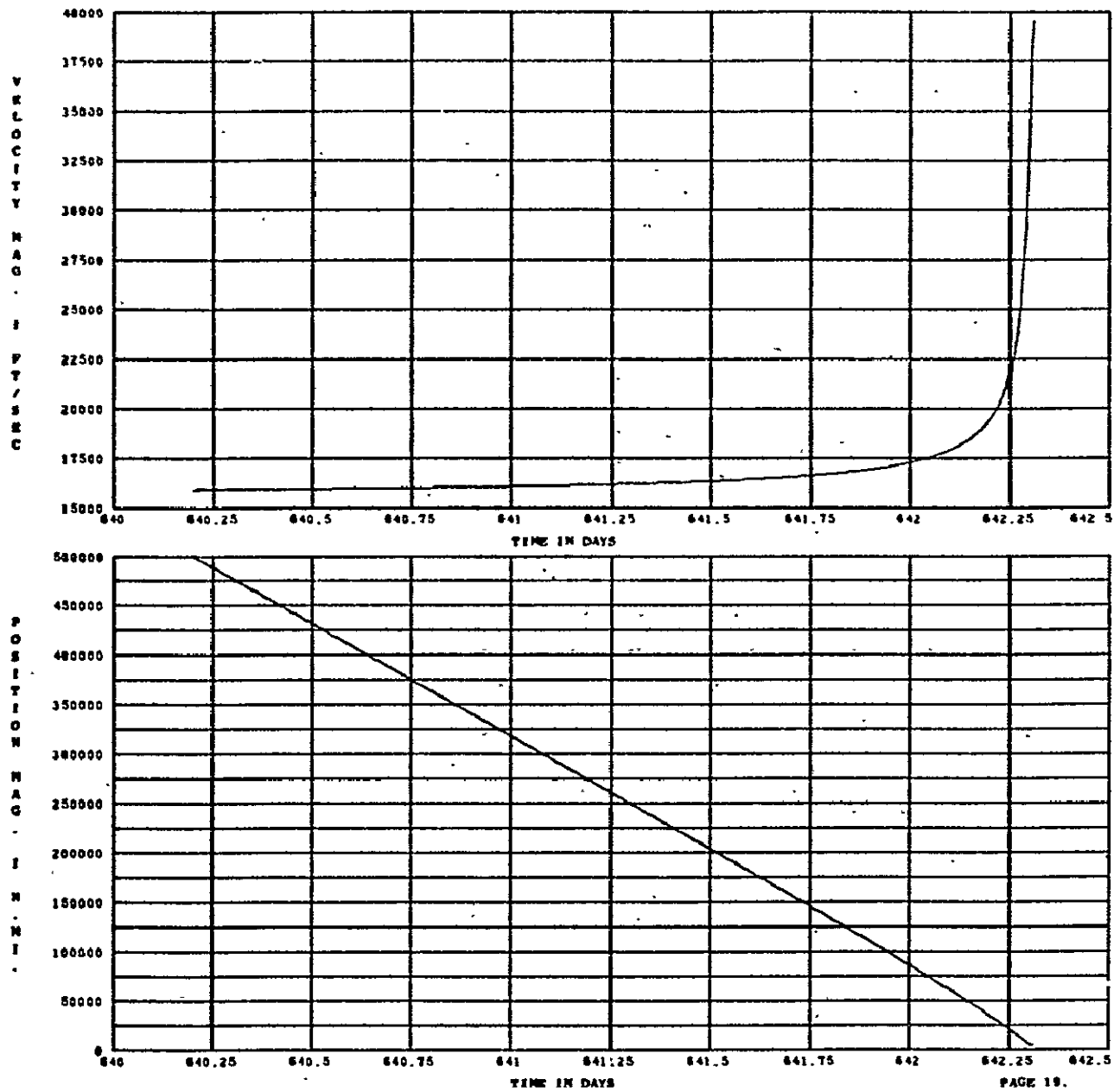
(b) Time histories of the Cartesian components of the velocity vector.

Figure 40. - Continued.



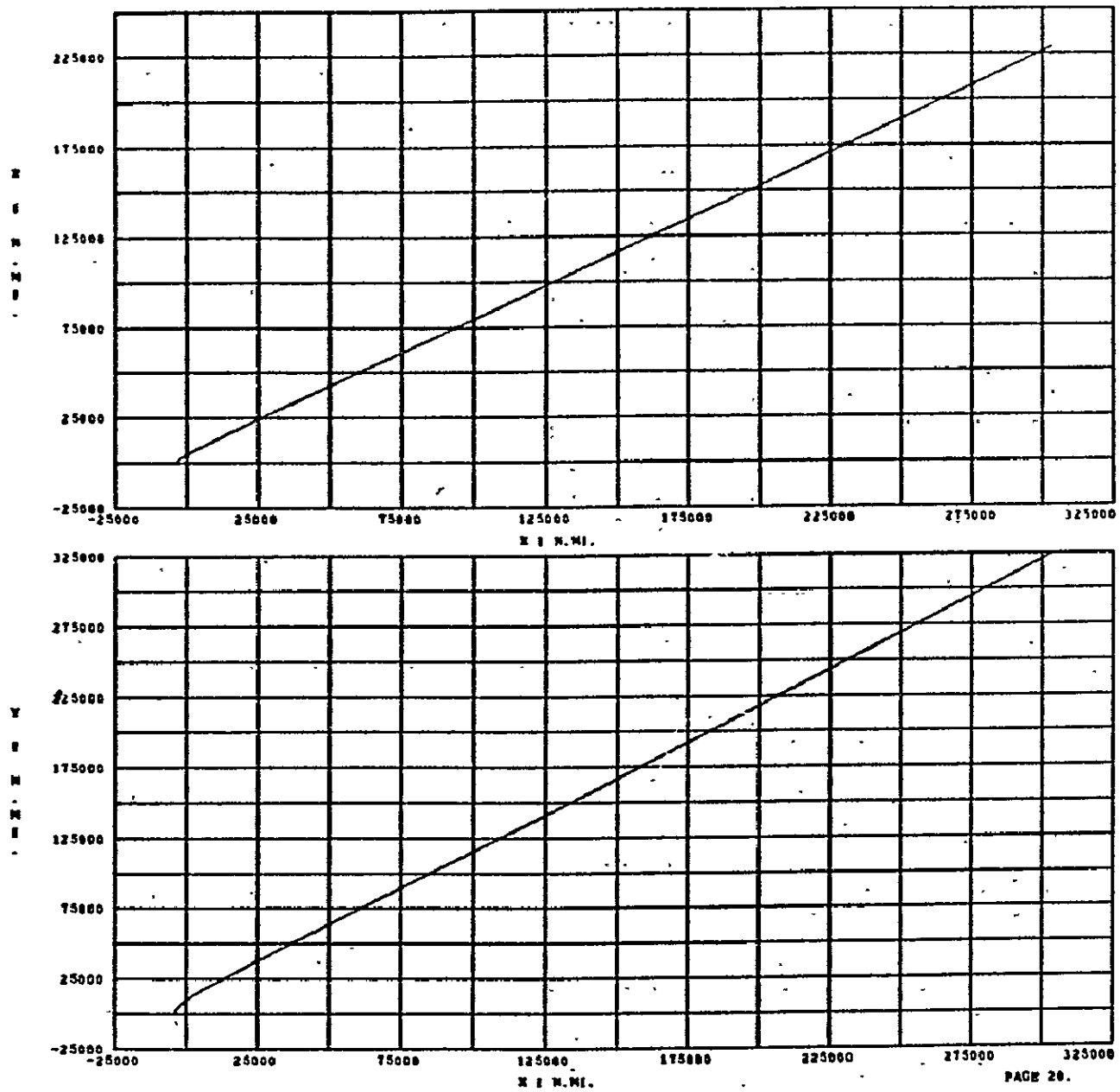
(c) Time histories of the true anomaly and mean anomaly.

Figure 40.- Continued.



(d) Time histories of the magnitudes of the position and velocity vectors,

Figure 40.- Continued.



(e) Trajectory projections on the X-Y and X-Z planes.

Figure 40.- Concluded.

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